

## Comparative Value of Germicidal Ices for Fish Preservation

BY H. L. A. TARR

*Pacific Fisheries Experimental Station  
Vancouver, B.C.*

(Received for publication January 11, 1947)

### ABSTRACT

The results obtained have shown that, in general, a germicidal ice which retards bacterial spoilage of fish is much more effective when the pH of the flesh is low than when it approaches the neutral point. Of the ices used those containing 0.1% sodium nitrite, 0.01 to 0.02% sulphanilamide, 0.01% sulphathiazole and 0.067% chloramine B plus 0.067% sodium benzoate were quite effective in delaying spoilage. Ices containing chloramine B, chloramine T, No-Bac, Rivanol, penicillin, Roccal and Emulsept retarded spoilage only slightly or not at all.

Much of the literature dealing with results of experiments in which attempts had been made to retard bacterial spoilage of fish by icing them with ices containing germicides was reviewed previously (Tarr and Bailey 1939). A brief report concerning the present work has been published (Tarr 1946).

Germicidal ices might be divided into two classes: eutectic ices in which the added germicide is distributed uniformly through the ice, and non-eutectic ices in which distribution is uneven. Few eutectic germicidal ices appear to have been described. Heiss and Cursiefen (1936-1937) prepared eutectic disodium phosphate ice (melting point about -0.9°C.) and eutectic sodium bicarbonate ice (m.p. about -2°C.), and found that fish iced with these ices did not spoil so rapidly as fish iced with ordinary ice. They attributed this finding to the fact that these ices maintained the fish at lower temperatures than did ordinary ice. The possibility that the rather alkaline solutions which formed when the ices melted exerted a mild bacteriostatic effect was apparently not considered. Bedford (Carter 1937, 1938 and unpublished) prepared an eutectic germicidal ice containing 0.16 per cent of benzoic acid. However, experiments showed that ice of this type effected no noticeable improvement in the bacteriological quality of iced fish, though it did specifically suppress trimethylamine formation (Tarr and Bailey 1939). Most of the germicidal ices which have been described have not been eutectic ices. In non-eutectic ices there is a strong tendency for the germicide to concentrate in the core of ice blocks during freezing, though a considerable quantity may be occluded throughout the ice mass, especially when solutions are not agitated (aerated) during freezing (Tarr and Sunderland 1940). Fine crushing and thorough mixing are necessary in order to obtain a fairly

uniform distribution of germicide throughout the crushed ice in the case of non-eutectic ices. Probably modern methods of ice manufacture in which small quantities of ice are rapidly frozen from a solution (e.g. the Flak-ice method) could readily be adopted for preparation of such ices.

#### EXPERIMENTAL

The following germicides were used: alkyl dimethyl benzyl ammonium chloride (Roccal), N-acyl (colamino formyl methyl) pyridinium chloride (Emul-sept), 2-ethoxy-6,9-diaminoacridine lactate (Rivanol), p-aminobenzenesulphonamide (sulphanilamide), 2-sulphanilyl-aminothiazole (sulphathiazole), sodium benzene-sulphonchloramide (chloramine B), sodium p-toluenesulphonchloramide (chloramine T), sodium penicillin, sodium benzoate, sodium nitrite and No-Bac (a commercial powder containing chloramine T and sodium benzoate). Frandsen (1946) has recently obtained a patent covering the manufacture of ice of this type under the trade name "Nipicide".

No attempt was made to prepare eutectic ices from any of these germicides. They were used in concentrations which would normally not increase excessively the cost of ice manufacture, which in aqueous solution were known in most instances to be actively bacteriostatic or bactericidal, and which would permit comparison with any available data from similar previous experiments. The ices were made either in commercial plants, the conditions of preparation being similar to those previously described (Tarr and Sunderland 1940), or by freezing about 15 kg. of solution in a galvanized iron container in still air at about  $-28^{\circ}\text{C}$ . The ices were crushed, mixed and stored at about  $-20^{\circ}\text{C}$ .

Analyses of approximately 2 kg. quantities of crushed ice were made in some cases in order to ascertain whether the added germicide was fairly well distributed. The following methods of analysis were used: that of the Rubicon Company (1939) for sulphanilamide, of White (1939) for sodium nitrite, and of Krog and Marshall (1940) for Roccal; and available chlorine in chloramine-containing solutions by the usual method involving liberation of iodine in acid potassium iodide solution, and titration of the iodine with standard sodium thiosulphate solution. The results of these analyses are given in brackets after the name and concentration of the compound used in preparing the ice (table I). They show that the recovery by analysis was lower than that expected from the quantity of germicide added in all except the 0.01% sulphanilamide ice, thus indicating an uneven distribution of the added chemical. Tests have shown that at  $0^{\circ}\text{C}$ . the solubility of sulphanilamide in water is about 0.2% and of sulphathiazole 0.015%.

The fish employed (table I) were, with the exception of the coho salmon, strictly fresh. They were obtained specially for the experiments and were iced, without being dressed, for less than a day before use. Most of the fish were still in rigor when they were iced in the experimental ices. The history of the coho salmon was not known. They were obtained from a local company and had been dressed, but not beheaded, and were stored in ice. They were only in fair condition and were typical of much of the fish of this type which is filleted. There

TABLE I. Comparative rate of spoilage of fish iced with various germicidal ices.

Species and composition of ice used	Init. pH of flesh	Bacteria in millions per g. of flesh after					
		5	7	9	11	14	17 days
Butter soles ( <i>Isopsetta isolepis</i> ).....	6.0						
0.1% sodium nitrite (0.076%) ..		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
0.067% chloramine B (0.06%) + 0.067% sodium benzoate.....		<0.1	<0.1	<0.1	<0.1	<0.1	1.4
0.0134% sulphanilamide.....		<0.1	<0.1	<0.1	<0.1	0.21	0.27
0.067% chloramine B (0.064%) ..		<0.1	<0.1	0.2	0.45	5.3	
0.00067% Rivanol.....		<0.1	<0.1	0.61	1.9	12.0	
Water (control).....		<0.1	<0.1	0.27	0.69	5.0	21
Lemon soles ( <i>Parophrys vetulus</i> ).....	6.2	5	7	10	12	14	17 days
0.1% sodium nitrite (0.076%) ..		<0.1	<0.1	<0.1	0.12	7.7	40
0.05% No-Bac.....		<0.1	<0.1	1.2	18	240	*
0.01% Roccal (0.0084%).....		<0.1	<0.1	<0.1	1.4	60	*
0.02% Roccal (0.0166%).....		<0.1	<0.1	1.2	22	73	*
0.02% Emulsept.....		<0.1	<0.1	1.1	29	53	*
Water (control).....		<0.1	0.13	2.3	38	194	*
Coho salmon ( <i>Oncorhynchus kisutch</i> ).....	6.2	4	7	9	11		days
0.1% sodium nitrite (0.088%)...		<0.1	0.42	0.99	4.4		
0.01% sulphathiazole.....		0.34	2.2	2.1	3.0		
0.01% sulphanilamide (0.01%)..		1.15	1.3	1.9	2.0		
0.2% chloramine B (0.193%) ..		<0.1	0.86	2.0	1.7		
220 International units of peni- cillin per g.....		0.64	2.1	3.6	2.5		
Water (control).....		0.19	1.5	3.3	7.2		
Starry flounder ( <i>Platichthys stellatus</i> ).....	6.5	5	7	9	13	15	17 days
0.1% sodium nitrite (0.088%)...		<0.1	<0.1	0.16	0.21	0.33	3.0
0.01% sulphathiazole.....		<0.1	<0.1	<0.1	<0.1	<0.1	1.0
0.01% sulphanilamide (0.01%)..		<0.1	<0.1	<0.1	<0.1	2.1	1.3
0.02% sulphanilamide.....		<0.1	<0.1	<0.1	<0.1	0.14	3.2
220 International units of peni- cillin per g.....		<0.1	<0.1	0.66	1.1	3.2	0.85
Water (control).....		<0.1	<0.1	2.0	0.58	0.80	5.0

\*These fish were putrid and no counts were made.

TABLE I Comparative rate of spoilage of fish iced with various germicidal ices.

Species and composition of ice used	Init. pH of flesh	Bacteria in millions per g. of flesh after					
		4	6	8	11	13	15 days
Whiting ( <i>Theragra chalcogramma</i> ) . . . . .	6.5	<0.1	<0.1	<0.1	0.13	1.2	3.4
		<0.1	<0.1	<0.1	0.27	1.8	8.2
		<0.1	<0.1	0.27	2.2	9.8	29
		<0.1	<0.1	0.17	1.0	26	34
		<0.1	<0.1	0.53	1.5	5.6	34
		<0.1	<0.1	0.45	2.1	2.4	19
Lingcod ( <i>Ophiodon elongatus</i> ) . . . . .	6.6						
			0.32	0.74	1.1	16	
			0.72	1.2	0.93	11	
			<0.1	0.29	3.6	4.0	
			0.16	0.82	3.0	12.0	
			2.4	2.2	3.7	7.7	
			2.4	1.9	7.0	8.2	

was some variation in the method of treating the fish prior to icing. In order to simulate commercial practice neither butter soles nor starry flounders were washed or dressed before they were iced. Lingcod and whiting were dressed and the belly cavities washed well, but the external slime was not removed before icing. The coho salmon were re-iced without washing and the lemon soles were dressed, washed thoroughly and then iced. Four or six fish were iced with from 10 to 12 kg. of crushed ice in 27 × 27 × 38-cm. boxes, six boxes of fish being stored in each experiment in a well-insulated cabinet. It was found that under these conditions the ices melted slowly and that the air temperature was approximately 1.5°C.

The relative rates of bacterial spoilage of the iced fish were determined as follows. A single fish was removed from each box and, except with lemon soles, was washed well with running tap water. It was filleted on a clean board and the fillets skinned. Both fillets, or a representative portion thereof not exceeding 200 g., were ground to a paste in a Waring blender, and water equivalent in weight to three times that of the ground fish was carefully stirred in so that incorporation of small bubbles was avoided. Direct bacterial counts (Tarr 1943) were made using this ground muscle suspension. This method is not accurate when there are less than about 100,000 bacteria per gram of flesh, unless a very large number of microscopic fields are counted. For this reason counts which were below this value were recorded as such. The initial pH of the mixed minced flesh of two

or three fish of each species investigated was determined using a Beckman pH meter. The results of these experiments are given in tables I and II.

Ice containing sodium nitrite was tested with each variety of fish for comparative purposes, because it had in previous experiments proven quite effective in retarding bacterial spoilage of four species of fish (Tarr and Sunderland 1940, 1941). The present experiments show that sodium nitrite ice markedly delayed spoilage of both butter and lemon soles in which the initial pH of the flesh was comparatively low. The fact that the coho salmon, which had a flesh pH value similar to that of lemon soles, were not nearly as effectively preserved by this ice, is probably explained by the fact that the fish were not very fresh at the commencement of the experiment, and that bacteria may have penetrated deeply into the muscle before the nitrite became sufficiently concentrated to exert a bacteriostatic effect. Sodium nitrite ice was considerably less effective in retarding bacterial spoilage of starry flounders and whiting than that of the lemon and butter soles in which the flesh was less acid, and only slightly delayed spoilage of lingcod which had the highest initial flesh pH value of any of the species investigated. Ice containing sulphanilamide markedly improved the keeping quality of butter soles, and also, though to a less marked extent, that of starry flounders. Ice of this type delayed bacterial spoilage of lingcod only slightly, and was ineffective in the case of coho salmon. Sulphathiazole ice effectively delayed spoilage of the starry flounders but not of the coho salmon. A slight improvement in the keeping quality of butter soles was occasioned by use of ice containing 0.067% chloramine B, but ice containing 0.2% of this compound did not delay the spoilage of the coho salmon. No improvement in the keeping quality of the lingcod was observed when chloramine T ice was used. Ice containing chloramine B plus sodium benzoate was more effective in retarding bacterial spoilage of butter soles than was ice containing only chloramine B, but it was practically ineffective with lingcod. No-Bac ice improved slightly the keeping quality of lemon soles and whiting, but was considerably less effective than sodium nitrite ice, especially with the lemon soles. Ices containing Roccal, Emulsept, sodium penicillin and Rivanol did not retard bacterial spoilage appreciably.

#### DISCUSSION

Although only one fish of each species has been examined at each time interval, the increase in number of bacteria in one type of ice is probably sufficiently consistent to justify the conclusions reached.

In general the results obtained show that ices of the type employed were not all effective, and those that were effective were most active when used on strictly fresh fish in which the initial flesh pH was quite low. Sodium benzoate (Cruess 1932), sodium nitrite (Tarr 1941), penicillic acid and 4-methoxy-2, 5 toluquinone (Tarr 1944) are most efficient as germicides when used in acid solution, and it is possible that this is true for certain of the germicides used in the present experiments. Probably the principal factors which determine the effectiveness of a germicidal ice in retarding bacterial spoilage of fish are the freshness of the fish used, the pH of its flesh and the ability of the germicide to penetrate unaltered

into the muscle. Thus sodium nitrite is quite effective because it diffuses into the flesh of iced fish (Tarr and Sunderland 1940, 1941) and is not affected by the flesh. It is not known whether sulphanilamide and sulphathiazole penetrate into the muscle of iced fish, but germicidal ices prepared from low concentrations of these compounds retarded bacterial spoilage quite markedly. Chloramines, though very powerful germicides, are readily inactivated in the presence of muscle tissue, and were not very effective in the present tests unless used in combination with sodium benzoate. In connection with the use of chloramines in ice it is of interest that a British patent covering the use of chloramine and dichloramine in ice was granted to DuPont de Nemours (1934). It has been shown that cationic detergent germicides are readily inactivated by phospholipids (Baker, Harrison and Miller 1941), and this may account for the ineffectiveness of ices containing Roccal and Emulsept in retarding bacterial spoilage. The lack of effectiveness of penicillin-containing ice might be due to the rather low concentration used or to the possibility that fish spoilage bacteria are not sensitive to this germicide. Rivanol ice was also ineffective, but the concentration used was very low. The results obtained with this compound are not in agreement with those of Keller (1940) who claimed that similar concentrations of Entozon in germicidal ice caused a very pronounced inhibition in the rate of bacterial spoilage of fish. Entozon contains Rivanol (29.44%), another acridine dye (5.88%) and sodium biborate (5.88%) as germicidal ingredients.

In conclusion it is desirable to point out that a germicidal ice may create a false impression of its true effectiveness by suppressing the formation of certain odoriferous substances associated with spoiling fish. Thus benzoic acid ice (Tarr and Bailey 1939) strongly suppressed trimethylamine formation in the flesh of iced fish without appreciably hindering the multiplication of bacteria.

#### ACKNOWLEDGEMENTS

I am indebted to the Winthrop Chemical Co. for supplying the Roccal, to the Solvay Process Co. for the Chloramine B, to the Canadian Fishing Co. and the Vancouver Ice and Cold Storage, Ltd., for freezing certain of the ices employed, and to Mrs. F. M. Kwong for technical assistance.

#### REFERENCES

- BAKER, Z., R. W. HARRISON AND B. F. MILLER. *J. Exper. Med.* **74**, 621-637, 1941.
- CARTER, N. M. *Ann. Rep. Biol. Bd. Can.*, **1936**, 36-37, 1937.  
*Ann. Rep. Biol. Bd. Can.*, **1937**, 55-56, 1938.
- CRUESS, W. V. *Ind. Eng. Chem.*, **24**, 648-649, 1932.
- DU PONT DE NEMOURS. *Brit. Patent No. 408, 696*, 1934.
- FRAANDSEN, L. *U.S. Patent No. 2, 398, 781*, 1946.
- HEISS, R. AND W. CURSIEFEN. *Jahresb. Kältetechn. Inst. Karlsruhe*, 729-731, 1936-1937.
- KELLER, VON H. *Vorratspflege u. Lebensmittelorschung*, **3**, 193-206, 1940.
- KROG, A. J., AND C. G. MARSHALL. *Amer. J. Pub. Health*, **30**, 341-348, 1940.

- RUBICON COMPANY. Evelyn photoelectric colorimeter, notes on operation, 1-40, Philadelphia, 1939.
- TARR, H. L. A. *Nature*, **147**, 417-418, 1941.  
*J. Fish. Res. Bd. Can.*, **6**, 119-128, 1943.  
*J. Fish. Res. Bd. Can.*, **6**, 257-266, 1944.  
*Fish. Res. Bd. Can. Prog. Rep. Pac.*, **67**, 36-40, 1946.
- TARR, H. L. A., AND B. E. BAILEY. *J. Fish. Res. Bd. Can.*, **4**, 327-336, 1939.
- TARR, H. L. A., AND P. A. SUNDERLAND. *J. Fish. Res. Bd. Can.*, **5**, 36-42, 1940.  
*J. Fish. Res. Bd. Can.*, **5**, 244-248, 1941.
- WHITE, W. H. *Can. J. Res.*, **17D**, 125-136, 1939.

## Differentiation of Marine and Non-Marine Cultures of *Pseudomonas*

BY C. H. CASTELL  
*Atlantic Fisheries Experimental Station*  
*Halifax, N.S.*

(Received for publication May 5, 1947)

### ABSTRACT

Cultures of *Pseudomonas* isolated from marine sources grew in sea water and died out in fresh water. Cultures of *Pseudomonas* isolated from non-marine sources died out in sea water and grew in fresh water. The addition of small amounts of peptone interfered with this inhibiting action of both sea water and fresh water.

The terms "marine" and "terrestrial" are frequently used to differentiate between those bacteria which have their origin in the ocean and those which are of land or fresh-water origin. The question is frequently asked whether any significance, other than the place of origin, can be attached to these terms. A very large number of the bacterial species isolated from the ocean have corresponding species that can be readily isolated from soil, fresh water and other non-marine sources. Is there any fundamental difference between these types?

ZoBell (1946, pp. 114-128) has pointed out that as a group, the marine bacteria differ in many ways from non-marine bacteria. They contain a larger number of gram-negative species; they are more subject to pleomorphism; they include fewer spore-forming species but more chromogenic types; the vast majority are facultative anaerobes; and their temperature requirements are considerably lower than land forms.

These facts do not indicate that specific bacteria of land and sea origin have any fundamental difference. They point only to the selective action of the sea in permitting the growth of a limited number of species. None of these characteristics, either alone or in combination, will determine whether a particular culture is of land or marine origin.

One of the extraordinary characteristics of the ocean is the uniformity of its constituents. From the standpoint of a bacteriologist, nowhere can we find another bacterial habitat so large, so little subject to change over tremendous periods of time. It would be surprising if strains and species of bacteria did not become closely adapted to this unchanging environment.

One would expect, therefore, that if marine bacteria have a differentiating characteristic it may be in their relationship to the salt content of their substrate, and particularly to sodium chloride.

ZoBell (1946, pp. 43-48) has shown that much higher total counts are obtained from sea water and ocean sediments when the plating medium and the dilution blanks are prepared with saline solutions or sea water. And, conversely, that inland soil, sewage, etc., yield much higher counts when fresh water is used. But can this relationship be used to differentiate specific cultures that have been isolated from marine and non-marine sources, but which otherwise have similar cultural characteristics?

The work recorded in this paper is concerned with 45 pure cultures of *Pseudomonas* isolated from marine and non-marine sources. An attempt has been made to determine whether their salinity relationships can be used as a method of indicating their natural habitat.

#### ISOLATION AND SELECTION OF CULTURES

Forty-five cultures of green fluorescent bacteria, having the characteristics of the genus *Pseudomonas*, were arranged into two groups: 1. Those definitely known to be of marine origin, isolated from water at sea or from the slime of fish immediately after being caught. 2. Those definitely known to be of non-marine origin, isolated from inland soil, fresh-water ice and from lakes and rivers.

Because of the confusion regarding the classification of *Pseudomonas* into species (Gaby 1946, Salvin and Lewis 1946, Seleen and Stark 1943), no attempt was made to identify each culture. However, they were all tested for pigment production on Georgia and Poe's medium (1931) and in Gessard's medium (Seleen and Stark 1943); also for their action in milk and gelatin, the reduction of nitrates to nitrites, and for the production of hydrogen sulphide and indol. The characteristics of their growth and colony formation were also observed. None of these reactions, alone or in combination, separated the marine from the non-marine cultures.

#### TRIMETHYLAMINE OXIDE REDUCTION

Baird and Wood (1944) examined over a hundred cultures of *Micrococci*, including 30 different species, for their ability to reduce trimethylamine oxide. These were obtained from various stock culture collections, presumably of non-marine origin. None of these cultures reduced the oxide. However, they observed that among the *Micrococci* isolated from marine fish many were able to reduce trimethylamine oxide. This suggests a specific cultural characteristic that may be related to the habitat of the bacteria. In unpublished work at this station, F. E. Dyer has found cultures of *M. aureus*, *M. aurantiacus*, etc., of marine origin which were able to reduce the oxide.

Using the methods of Wood and Baird (1943) the *Pseudomonas* cultures were tested for trimethylamine oxide reduction. They were all negative.

#### OXIDATION REDUCTION POTENTIAL CURVES

Burrows (1941) has successfully used time-Eh curves in a standard medium to differentiate closely related species of the genus *Salmonella*.

Similar measurements were made with 6 cultures of *Pseudomonas* isolated from fresh water ice and cod fish slime. The ordinary cultural characteristics of these organisms were identical. The medium used contained 0.1% peptone and 0.05% each of dextrose, yeast extract and sodium chloride. The measurements were made in duplicate with coiled platinum electrodes. The range at which the potential curves levelled off was between -0.12 and -0.13 volts, and was approximately the same for all six cultures, regardless of their origin.

#### SALT TOLERANCE TESTS

Using a medium composed of 0.5% each of peptone and yeast extract in distilled water, sodium chloride was added to give the following concentrations (w/v): 0, 1, 3, 5, 6, 7 and 8%. Each of these solutions was inoculated in duplicate with the 86 *Pseudomonas* cultures and incubated at 25°C. for 8 days.

All the organisms grew vigorously in the presence of 1 and 3% salt. Seventy-five % of the marine cultures and 88 % of the non-marine cultures grew in the tubes containing 5% sodium chloride. Fifty-two % of the marine cultures and 64% of the non-marine cultures grew in 6% solutions. Up to 8 days there was no growth in any of the tubes containing 7 or 8% sodium chloride.

After 8 days' incubation at 25°C., one ml. transfers were made from all the tubes showing no growth into sterile salt-free broth. In every case, active growth developed in inoculated tubes, showing that those concentrations of salt which inhibited growth did not destroy the cultures in the period used.

These results indicate that similar organisms of marine and non-marine sources cannot be differentiated by their tolerance to sodium chloride.

#### GROWTH IN SEAWATER AND TAPWATER

Members of the genus *Pseudomonas* are among the organisms capable of multiplying in ordinary natural waters without the addition of extra nutrients (Castell and McDermott 1942). It would seem probable that if fresh or sea water were able to exert a detrimental action on bacteria, it might be most effective in its natural state, without the addition of nutrients and other materials that will poise, buffer or otherwise mask its characteristics.

For these tests, 16 similar cultures were used. Four were obtained from ice cut from a fresh-water lake; four were obtained from river water; the remaining eight were taken at sea from the slime and moisture on the surface of freshly-caught cod fish. All these cultures were actively motile, liquefied gelatin, completely peptonized milk, did not reduce nitrates to nitrites, and did not produce either indol or hydrogen sulphide.

Flasks (500 ml.) of autoclaved sea water and autoclaved tap water were inoculated from suspensions made from each culture. Plate counts were made on each water sample immediately after inoculation and again after 10 days' standing at room temperature.

The results (table I) show that most of the cultures obtained from the fish slime increased in the sea water and died out in the fresh water. And, conversely, those of fresh water origin decreased in the sea water and increased in the tap water.

TABLE I. Multiplication of cultures of *Pseudomonas*, of marine and fresh water origin, in autoclaved sea and fresh waters.

Origin	Initial count	Count after standing 10 days	
		Sea water	Tap water
Fish slime 1	10,400	2,400,000	0
" " 2	33,400	30,000	0
" " 3	17,200	187,000	0
" " 4	12,400	15,700	0
" " 5	34,400	78,200	72
" " 6	7,800	1,370,000	300
" " 7	12,000	32,000	0
" " 8	328	620,000	0
River water 1	5,700	0	11,300
" " 2	121	0	2,500
" " 3	14,300	13	120,000
" " 4	96,000	860	860,000
Ice 1	32,000	0	960,000
" 2	9,800	0	450,000
" 3	7,100	0	13,700
" 4	27,200	0	192,000

In order to obtain a more detailed picture, two marine and two non-marine cultures were inoculated into sea and tap water, and plate counts were made periodically up to 6 days' incubation at 25°C. As well as using ordinary nutrient

TABLE II. The multiplication of 2 marine and 2 non-marine cultures of *Pseudomonas* in autoclaved sea and tap waters.

Incubation period (hours)	Bacterial plate counts (no. per ml.)							
	In sea water				In tap water			
	S53*	S40*	F65†	F13†	S53	S40	F65	F13
0	200	1,300	3,060	3,000	1,064	2,600	2,300	3,600
6	402	4,400	540	122	1,600	2,300	6,300	2,000
24	200	1,700	4	0	285	900	80,000	70,000
72	100	2,500	0	1	156	2	200,000	170,000
78	300	350,000	2	0	141	0	320,000	130,000
96	1,200	360,000	2	1	26	0	620,000	510,000
102	3,900	409,000	0	0	8	0	570,000	450,000
120	7,000	300,000	0	0	0	0	380,000	250,000
126	7,000	290,000	0	0	0	0	450,000	390,000

\*Cultures from fish slime.

†Cultures from fresh water ice.

agar, plate counts were made with ZoBell's special medium (ZoBell 1946, p. 41) for growing marine organisms. An attempt was also made to reduce the number of cells in the initial inoculation to a range that would give something under 1,000 per ml. in the water.

The results obtained confirmed the previous tests. Table II gives the counts in the nutrient agar. Those on ZoBell's medium were almost identical.

Marine and non-marine cultures of *Pseudomonas* which had been carried as stock cultures on agar slants for over two years retained their tendency to grow in one type of water and die out in the other.

#### ADDED NUTRIENTS

The addition of nutrients removes the selective action of both sea and tap waters for these organisms. In ordinary culture media, sea water may be replaced with tap water, without having any detrimental effect on the growth of marine strains of *Pseudomonas*.

A series of tests was made in which graded amounts of Neopeptone were added to sea water and tap water, and then inoculated with marine and non-marine strains of *Pseudomonas*. Sufficient resazurin was added to give the water a faint pink colour, in hopes that a reduction of this dye might be used to indicate growth of the bacteria.

The amounts of peptone used ranged from 1 in 10,000 to 1 in 10,000,000 parts of water (w/v). The cultures used were the same as those in the previous experiment—two marine and two non-marine types. The organisms were cultured in a peptone solution. The maximum possible addition of peptone to the water from the inoculum was in the order of 1 part in 10,000,000.

The flasks of water were examined daily for two weeks and those developing sufficient numbers of cells to give the liquid a perceptible cloudiness when the flasks were placed in a strong beam of light were recorded. At the end of this period, all those which did not develop this cloudiness were plated out on nutrient agar to determine the number of viable cells present at this time.

The results (table III) show that with one part of peptone in 100,000 parts of water, sufficient growth was obtained to give the liquid a faint cloudy appearance, irrespective of the type of water or the origin of the cultures. The plate counts indicate that even smaller amounts of peptone (either alone or in combination with the indicator) overcame the selective action of waters.

Other tests, similar to these, using resazurin or methylene blue gave approximately the same results. With the concentration of peptone at 1 part in 1,000 or greater, the indicators were reduced; with 1 part in 10,000 they were occasionally partly reduced. But there was no relationship between the reduction of the dye, the type of water and the origin of the cultures. Quite frequently sufficient growth to produce slight cloudiness appeared sooner, and extended one dilution lower when the sea organisms were grown in the peptone-sea water or the fresh-water organisms in the peptone-tap water solutions. But this was not constant enough to be a means of differentiating the sea and fresh-water organisms.

TABLE III. Growth of marine and non-marine *Pseudomonas* cultures in sea and tap water containing graded amounts of peptone as indicated by cloudiness or plate counts per ml.

Culture	Type of water	Concentration of peptone in the water			
		10 <sup>-4</sup>	10 <sup>-5</sup>	10 <sup>-6</sup>	10 <sup>-7</sup>
S53	Sea	C	C	22 × 10 <sup>6</sup>	20 × 10 <sup>6</sup>
	Tap	C	43 × 10 <sup>6</sup>	22 × 10 <sup>6</sup>	30 × 10 <sup>6</sup>
S40	Sea	C	C	8 × 10 <sup>6</sup>	6 × 10 <sup>6</sup>
	Tap	C	C	14 × 10 <sup>6</sup>	11 × 10 <sup>6</sup>
F65	Sea	C	C	9 × 10 <sup>6</sup>	15 × 10 <sup>6</sup>
	Tap	C	C	C	24 × 10 <sup>6</sup>
F13	Sea	C	C	17 × 10 <sup>6</sup>	7 × 10 <sup>6</sup>

C, sufficient growth to produce cloudiness.

\*Cultures marked F are of non-marine origin; those marked S are of marine origin.

The use of dextrose and other sugars in place of peptone did not result in overcoming the selective action of the sea and fresh waters for their respective cultures of bacteria.

#### DISCUSSION

It has long been known that there is both a similarity and a difference between the microflora of the sea and that of the soil or fresh water. This is to be expected, just as there is a characteristic microflora of milk products which differs from that of beer or fish. The type of nutrients present, and the influence of various physical and chemical factors of the substrate tend to select certain groups of organisms and to inhibit others. But there have been few observations to indicate that apparently similar cultures from milk and beer have differences that can be traced to their habitat. However, through a gradual process of selection during a period of centuries or more, beer and wine yeasts have been produced that can withstand much greater concentrations of alcohol than apparently identical strains isolated from other sources.

It would seem that both sea water and fresh water have had a similar selective action on strains of *Pseudomonas* which are otherwise very similar. The surprising part is that the addition of relatively small amounts of nitrogenous material overcomes this characteristic.

From a practical standpoint, whether the organisms are of fresh-water or sea-water origin it will make little difference in their ability to attack fish muscle or other organic food materials.

These observations must not be confused with another type of bactericidal action that sea water has been shown to have on various bacteria. Sea water has a thermolabile, filter-passing agent that is toxic for many bacteria. Protozoa and other marine animals in sea water are known to ingest bacteria, and thus reduce their numbers. But neither of these agents can be responsible for the decreases in bacteria described above. All the water samples used had been carefully autoclaved.

## SUMMARY

- (1) Ordinary cultural characteristics, salt tolerance, characteristic potentials or the reduction of trimethylamine oxide did not differentiate between *Pseudomonas* cultures of marine and fresh water origin.
- (2) Marine types multiplied in autoclaved sea water and died out in autoclaved tap water. Fresh water types acted conversely.
- (3) The addition of traces of peptone (but not dextrose) overcame this selective action of sea and tap water.

## REFERENCES

- BAIRD, E. A., AND A. J. WOOD. *J. Fish. Res. Bd. Can.*, **6**, 243-244, 1944.  
BURROWS, W. *J. Infect. Diseases*, **69**, 141-147, 1941.  
CASTELL, C. H., AND L. McDERMOTT. *Food Res.*, **7**, 244-253, 1942.  
GABY, W. L. *J. Bact.*, **51**, 217-234, 1946.  
GEORGIA, F. R., AND C. F. POE. *J. Bact.*, **22**, 349-361, 1931.  
SALVIN, S. B., AND M. L. LEWIS. *J. Bact.*, **51**, 495-506, 1946.  
SELEEN, W. A., AND C. N. STARK. *J. Bact.*, **46**, 491-500, 1943.  
WOOD, A. J., AND E. A. BAIRD. *J. Fish. Res. Bd. Can.*, **6**, 194-201, 1943.  
ZOBELL, C. E. *Marine microbiology*. 1-240, Chronica Botanica Co., Waltham, Mass., 1946.

## Cruising Speed of Goldfish in Relation to Water Temperature

By  
F. E. J. FRY  
AND  
J. S. HART

*Department of Zoology, University of Toronto*

(Received for publication March 22, 1947)

### ABSTRACT

When goldfish are placed in a rotating annular chamber of which the outer wall is glass, they can be induced to swim steadily at a rate which varies with the temperature when the water is aerated. When the subjects have been in each case previously acclimated to the experimental temperature the best performance is attained at temperatures from 20 to 30°C., the highest temperature to which goldfish can be acclimated being 41°C. Subjects acclimated to a variety of experimental temperatures gave curves of performance in relation to temperature which were unique for each level of acclimation.

### INTRODUCTION

Dr. H. M. Rogers (unpub.) performed some very interesting experiments in which he measured what he termed the cruising speed of the speckled trout, *Salvelinus fontinalis*, and of the creek shiner, *Notropis cornutus*, in relation to temperature. The cruising speed was taken as that speed at which the fish could swim steadily for some considerable period of time, although presumably after hours fatigue would set in. The analogy in man would be the pace that a runner maintains for the two to three hours which he spends in covering a marathon course.

In this work he found a definite optimum temperature for the cruising speed of the speckled trout at about 16°C. Rogers was not able to carry this work further at that time and since has unfortunately been killed on active service.

In view of the promise of this preliminary work of Rogers as a measure of animal activity in relation to an environmental factor, we have performed similar experiments on young goldfish in order to investigate the matter further.

### MATERIAL AND METHODS

The subjects used were young goldfish, *Carassius auratus* L., all purchased at one time from an Ontario breeder. The average weight of these fish at the time when the experiments were performed was 4.37 g. with a standard deviation of 0.96 g. All the experiments were carried out between October 25 and November 30.

Measurement of the cruising speed of these fish was carried out in a rotating annular chamber of which the outer wall was glass and the inner metal. The dimensions of the chamber were 12" O.D., 6" I.D., by 6" deep (1" equals 2.54 cm.). The oxygen supply was maintained and the temperature regulated by allowing aerated water at the desired temperature to flow through the chamber.

When the chamber was rotated the fish reacted by swimming to maintain place with reference to the room. This response, which presumably was primarily due to the effect of the short radius of rotation (Gray 1937), appeared also to be elicited by the animal's reaction to a lighted table lamp which was placed with the bulb approximately at the eye level of the fish and about two feet (1 foot equals 0.30 m.) away from the chamber. The response was further promoted by the presence of a thermometer suspended from a stand so that the lower end was in the water of the chamber. The animals were also stimulated by tapping them lightly with a glass rod if they fell back beyond a certain point.

The speed of the water in relation to the speed of rotation of the chamber was determined by measuring the rate at which a loose ball of absorbent cotton about the size of a large walnut was carried around in the chamber under the conditions of the experiment. The relation thus obtained was a constant ratio of 0.582 : 1. No change in this ratio was found at different temperatures. The effort that the fish put forth in order to maintain place during one revolution of the chamber is estimated to represent that which is required to swim a distance of 2.5 feet. This distance is the circumference of a circle just under 9.5 inches in diameter which represents almost exactly a path described along the centre of the annular channel. All measurements given have been converted from revolutions of the chamber per minute to feet per minute swimming effort by the use of these factors.

The values obtained for cruising speeds in this apparatus are estimates rather than absolute measurements. The procedure was to introduce a fish into the chamber and rotate it at some 10 to 20 r.p.m. for a few minutes until the animal had settled down to swim steadily. During this period it was often necessary to apply the rod quite consistently. In 6 cases out of 82 trials the animals would not swim steadily and were discarded. When the subject was swimming steadily in the slowly rotating chamber the speed of rotation was increased by gradual steps until the animal consistently failed to keep pace. The rate of rotation was determined by counting the number of turns in one minute. During each such interval any rotations lost by the fish were noted. Including the time required to change the speed, the fish spent at least two minutes at each rotation speed and usually were swimming for 20 to 25 minutes before the rotation of the chamber had been speeded up to the point where the subject began to lose laps. By starting at a slow rate of rotation and gradually increasing the speed it was felt that the effect of fatigue was avoided. By requiring that the effort be maintained at least two minutes it was assumed that something of the order of a steady state was attained.

A typical protocol is reproduced in table I. A different fish was used for each determination and the results of three determinations averaged to give a value for the performance under a particular condition. Previous to the tests various lots of fish were subjected to constant temperatures at a level of either

5, 10, 15, 20, 25, 30, or 35 degrees Centigrade for a sufficient time (Brett 1946) for them to become thermally adapted to the particular level at which they were placed, in so far as that adaptation would be shown by the stability of the upper

TABLE I. Typical protocol of the measurement of the cruising speed of a goldfish in the rotating chamber. Acclimation temperature 25°C. Test temperature 25°C.

Time elapsed (min.)	Speed of rotation (r.p.m.)	Laps lost by fish per min.
7	44	0
9	51	0
11	59	0
13	66	0
15	69	0
17	66	0
19	74	0
21	80	3
23	80	15

Cruising speed taken to be  $74 \times 0.582 \times 2.5 = 107$  feet per minute.

lethal temperature. The fish were transferred directly from their acclimation bath to the rotating chamber. Throughout their acclimation period the fish were fed regularly on liver and fox chow.

#### RESULTS

The results obtained are summarised in table II. The experiments performed fall logically into two groups. In one group the cruising speeds were

TABLE II. The cruising speed of young goldfish in feet per minute in relation to their thermal history and to the water temperature at which the speed was measured. Each value is the average of three determinations each on a separate individual.

Acclim. temp. (°C.)	Test temperature (°C.)							
	5	10	15	20	25	30	35	38
5	44	58	68	68	41			
10		57						
15	44		71	79	77			
20				100				
25			55	79	96	100	68	
30				30	58	70	76	84
35								

measured at the temperature to which the fish had become acclimated. The results of these experiments are shown in figure 1. It will be seen in figure 1 that the cruising speed in thermally adapted animals was approximately 40 feet per

minute at 5°C. and rose rapidly to 100 f.p.m. at 20°C. From 20°C. to 30°C. there was practically no change in speed although it can be estimated by interpolation that the cruising speed would have reached a flat peak at some intermediate point. Above 30°C. the speed fell off, dropping to 75 f.p.m. by 35°C.

The second group of experiments embraces those in which the cruising speed of the fish was measured immediately after transference to some temperature other than that to which they had been acclimated. These experiments were carried out using four groups of fish acclimated respectively to temperatures of 5, 15, 25 and 35 degrees Centigrade. The results of these experiments are illustrated in figure 2. For comparison the curve in figure 1 is reproduced in figure 2 as a dotted line.

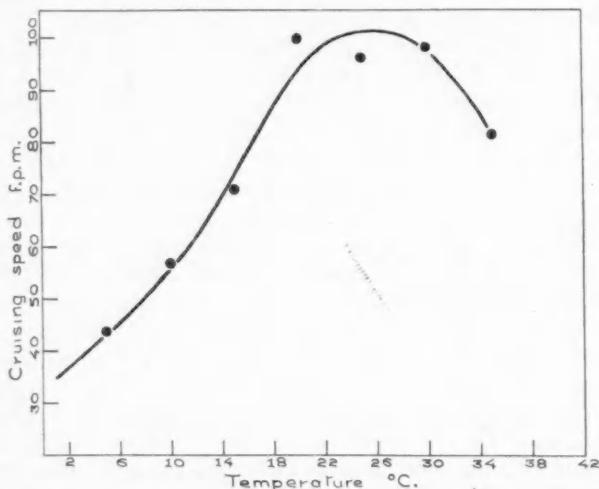


FIGURE 1. The relation between temperature and the rate at which goldfish can swim steadily to maintain place in a rotating chamber when they are acclimated to the temperature at which the test is carried out.

It will be seen in figure 2 that the four groups of fish each acclimated to a different temperature level gave four distinct curves over the range of experimental temperatures. Three of these curves show optima. The fourth, which is for fish acclimated to 35°C., continues to rise as far as the experiment was carried, although the animals were taken to within 3°C. of their upper incipient lethal temperature (Fry, Brett, and Clawson 1942).

#### DISCUSSION

The overall picture of the relation of cruising speed to water temperature in the goldfish is the same as that established previously for the speckled trout by Rogers, and it may be concluded that the trout is not unique in this respect. Indeed a similar relationship has been shown for the rate of progress in quite

another forced movement in a representative of another phylum. This is the rate of creeping of *Limax* during circus movements under constant illumination at different temperatures. (Crozier and Federighi 1924).

A feature of these curves which is usually ignored in the application of the well-known temperature indices is the upper portion beyond the maximum rate. In the case described here it is rather difficult to accept the usually offered explan-

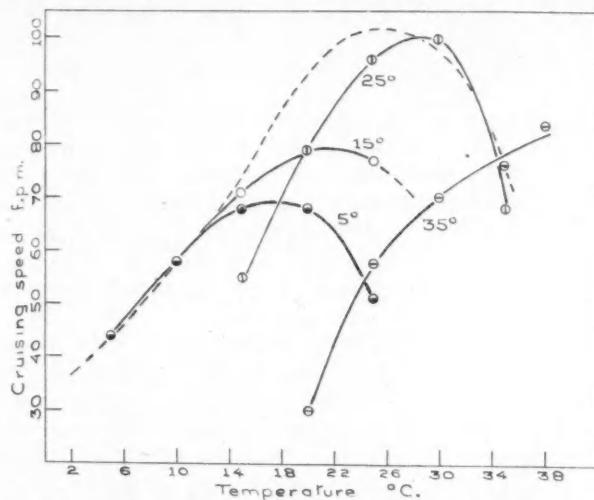


FIGURE 2. The relation between temperature and sustained swimming rate in goldfish acclimated to various levels of temperature and tested at various other temperatures. The dotted line is a reproduction of figure 1.

ation of thermal destruction, at least without definite proof that such is the case, since the maxima in both the acclimated and the unacclimated series come well below the incipient lethal temperature (Fry, Hart, and Walker 1946) as table III indicates. Consequently no analysis of these curves has been attempted at the present writing, the matter being deferred for further consideration.

TABLE III. Comparison between temperature of maximum cruising speed and lethal temperature in young goldfish. Lethal temperatures from Fry, Brett and Clawson 1942.

Acclimation temperature (°C.)	Temp. for max. cruis. speed (°C.)	Upper incipient lethal temp. (°C.)	Difference (°C.)
5	18	29.0	11
15	23	32.5	9.5
25	28	36.0	8
35	38+	41.0	3—
fully acclimated	28	41.0*	13

\*Ultimate upper incipient lethal temperature.

The profound effect of thermal acclimation on the cruising speed which is shown in figure 2 makes it necessary to define the level of thermal acclimation of any subjects on which this measurement is made. It would seem best, if this measurement of cruising speed in relation to temperature is to be used as a means of comparing species, to adapt thermally the subjects to each temperature at which it is desired to measure this aspect of their activity before the measurement is made. The curve presented then for comparison of the goldfish to other species is that in figure 1. Rogers' curve for the speckled trout is presumably of this type although it is possible that he did not always allow sufficient time for complete acclimation to each temperature.

The data here, together with previous work on the goldfish, allow for a further comparison of the temperature for peak activity with the preferred temperature. The belief has been expressed (Doudoroff 1938) that the preferred temperature has no particular relation to any temperature optimum for activity. On the other hand, Fisher and Elson (1940) have shown a close relation between the preferred temperature and the temperature at which the maximum response to a stimulus is obtained in the speckled trout. Workman and Fisher (1941) and Scott (unpub.) have reported the same correlation in Amphibia.

It is now possible to add another comparison, that between the preferendum of the goldfish and the optimum temperature for the cruising speed. Fry (unpub.) measured the preferred temperature of young goldfish in relation to their thermal history. The temperature at which the mode of distribution occurred was taken as indicating the preferred temperature. This temperature is in the region of the optimum temperature for the cruising speed in fully acclimated goldfish, and it seems probable that there is some connection between the two. He determined that the final preferendum, that temperature to which they would ultimately gravitate if left indefinitely in a gradient, was between 28 and 29°C.

However, there is no similar correspondence between the preferenda at various acclimation levels and the optimum temperature for activity in fish acclimated to the same levels. The peak cruising speed of the 5°C. acclimated fish was reached at about 18°C. By the extrapolation from 10°C. the preferendum for goldfish acclimated to the same level would be 20°C. For the sample acclimated to 15°C. the figures were, peak cruising 23°C., preferendum 26°C. The difference is not great in either of these two instances but in the samples acclimated to 35°C. the peak cruising speed was at 38°C. or higher, whereas the preferendum was at 28 to 29°C. At the 25°C. level of acclimation the figures coincide closely, no doubt because this level is close to 28°C.

#### SUMMARY

1. The cruising speed of young goldfish was measured by placing them in an annular glass walled chamber capable of being rotated at various speeds.
2. The cruising speed of goldfish which are thermally adapted to the temperature at which the speed is measured rises steeply over the temperature range from 5 to 20°C., remains fairly constant to 30°C., and then drops with considerable rapidity. It can be estimated by interpolation that a flat peak occurs in the neighbourhood of 28°C.

3. The cruising speeds of goldfish acclimated to temperature levels of 5, 15, 25, and 35°C. and measured over the biokinetic range appropriate to each level of acclimation, display four distinct curves.

4. The final preferendum for the goldfish and the optimum temperature for cruising speed in thermally adapted fish correspond closely.

5. The optimum temperature, however, is not sharply defined for thermally adapted fish perform almost equally well over the range from 20 to 30°C.

6. There is not always a direct correspondence between the optimum temperature for cruising speed and the preferendum in fish that are adapted to one particular temperature level.

#### REFERENCES

- BRETT, J. R. Rate of gain of heat-tolerance in goldfish (*Carassius auratus*). *Univ. Toronto Stud., Biol. Ser.* **53**, *Pub. Ont. Fish. Res. Lab.*, **64**, 5-23, 1946.
- CROZIER, W. J., AND H. FEDERIGHI. Phototropic circus movements of *Limax* as affected by temperature. *J. Gen. Physiol.*, **7**, 151-169, 1924.
- DUODOROFF, P. Reactions of marine fishes to temperature gradients. *Biol. Bull.*, **75**, 494-509, 1938.
- FISHER, K. C., AND P. F. ELSON. A possible mechanism for temperature preference in Atlantic salmon and speckled trout. *Proc. Roy. Soc. Can., (Abst.)* **34**, 168, 1940.
- FRY, F. E. J., J. R. BRETT AND G. H. CLAWSON. Lethal limits of temperature for young goldfish. *Rev. Canad. Biol.*, **1**, 50-56, 1942.
- FRY, F. E. J., J. S. HART AND K. F. WALKER. Lethal temperature relations for a sample of young speckled trout, *Salvelinus fontinalis*. *Univ. Toronto Stud., Biol. Ser.,* **54**, *Pub. Ont. Fish. Res. Lab.*, **66**, 5-35, 1946.
- GRAY, J. Pseudo-rheotropism in fishes. *J. Exper. Biol.*, **14**, 95-103, 1937.
- WORKMAN, G., AND K. C. FISHER. Temperature selection and the effect of temperature on movement in frog tadpoles. *Amer. J. Physiol.*, **133**, p. 499-500, 1941.

## Observations on the Lake Trout of Great Bear Lake

By R. B. MILLER

*University of Alberta*

AND

W. A. KENNEDY

*Central Fisheries Research Station, Winnipeg, Man.*

*Received for publication May 8, 1946)*

### ABSTRACT

The lake trout (*Cristivomer namaycush*) is the principal fish of Great Bear lake. The largest populations were found in semi-isolated bays, with smaller populations in the open lake on one hand and in river mouths and marshy areas on the other. The trout grow very slowly; by three years they are just over three inches (7.6 cm.) long and weigh one ounce (28 g.). A weight of one pound (0.45 kg.) is achieved in their ninth year and two pounds in their fourteenth year. Maturity is reached in from 13 to 17 years; the rate of growth in weight increases after maturity. Mature fish appear to spawn only every second or third year. Spawning begins about the middle of August. The young trout spend their first four summers in shallow water near shore. The adults feed on all food sources in the lake,—plankton, bottom organisms, fish and terrestrial insects. Fish preparing to spawn have pale flesh; others have orange to red flesh. There is some evidence of two morphologically distinct groups, probably resulting from environmental differences. A list of the parasites of the trout is given. A detailed analysis of the incidence of cysts of *Triaenophorus crassus* indicates that adult trout remain in one locality throughout life.

### INTRODUCTION

During the summer of 1945 the Fisheries Research Board of Canada carried out a survey of the fishery resources of Great Bear lake, N.W.T. The authors were two of the field party of three engaged in this survey. Early in the summer it became apparent that the lake trout, *Cristivomer namaycush* (Walbaum), was the principal fish of the lake. Gill nets and angling yielded 438 lake trout and an additional 55 young trout were collected by hand around the shores.

Great Bear lake lies about sixty miles east of the Mackenzie river and 400 miles north of the Alberta boundary (1 mile = 1.6 km.). The Arctic circle intersects its northern tip. It has an area of 11,800 square miles (1 sq. mile = 2.6 sq. km.) and, in places, the great depth of 1,300 feet; most of the lake is 400 feet or more in depth (1 ft. = 0.3 m.). The high and barren Precambrian Shield forms the shore line of the eastern third of the lake; the western two-thirds are in lower, rolling country bordering the Mackenzie lowlands.

The water is very cold; the ice cover does not break up until past the middle of June and ice remains on the lake in floes until late in July. Surface temper-

atures in the open lake reached  $12.9^{\circ}\text{C}$ . on August 30; temperatures below the surface remained near  $4^{\circ}\text{C}$ .

The pH was between the limits 7.2 and 7.4.

The transparency is very great; the Secchi disc was visible in open water on the east shore at a maximum depth of 96 feet.

Plankton and bottom fauna were poor. Total vertical hauls with a no. 20 silk plankton net, having a mouth 25 cm. in diameter, averaged only 21 mg. dry weight at  $50^{\circ}\text{C}$ . (analysis made by Dr. D. S. Rawson). Bottom samples in open water yielded no animals beyond 60 feet and less than 1 gram (live weight) per square foot (1 sq. ft. = 0.09 sq. m.) in shallower water. Somewhat larger amounts were found in protected localities. The records of the survey are on file in the Department of Zoology, University of Alberta, Edmonton.

#### DISTRIBUTION AND AVAILABILITY

The distribution and availability were studied by setting gangs of gillnets, which consisted of five nets each 50 yards (45.7 m.) long and about  $4\frac{1}{2}$  feet deep, respectively  $2\frac{1}{2}$ , 3, 4, 5 and  $5\frac{1}{2}$  in. (1 in. = 2.5 cm.) stretched mesh, at various places in Great Bear lake. Each set of one gang is considered to be a unit of fishing effort. Sixty-five sets were made on the bottom of the lake, and three sets by suspending the nets near the surface.

The localities fished seemed to fall into five groups: inshore area of the open lake; non-marshy bays; marshy bays; river mouths other than the Johnny Hoe; the Johnny Hoe river mouth.

The inshore area of the open lake comprises about 14% of the total area. It includes small bays whose temperature is the same as that of the open lake. Twenty-one sets were made in this type of habitat along the east shore, mostly near Port Radium. Most of the sets were in water less than 50 feet deep. No decrease in availability was apparent even in 400 feet of water,—the deepest fished. An average of 3.8 fish per set was taken with little variation between sets. The three off-bottom sets were made in this area. They caught nothing.

Non-marshy bays comprise about 2% of the total area. They are relatively shallow and sufficiently isolated from the open lake that the temperature is appreciably higher. Twenty-two sets were made in such places. In one bay—but not in the other bays—deep sets caught noticeably more lake trout than shallow sets, probably because this bay is almost completely isolated, and thermal stratification is pronounced. The availability did not vary appreciably from bay to bay. The average catch was 7.3 lake trout per set.

Marshy bays comprise about 0.2% of the total area. They are shallower, warmer and less transparent than the other habitats, and, except for one of them, are quite small. Ten sets were made in such areas; the availability did not vary appreciably from bay to bay. The average catch was 1.5 per set.

River mouths comprise about 0.1% of the total area. Eight sets were made; the availability did not vary appreciably from place to place. The average catch was 4.0 lake trout per set.

The availability at the Johnny Hoe river mouth was so much different from that at other river mouths that it is given separate treatment. An average of 11 lake trout per set were caught in the three sets that were made. This average is probably not comparable with the others since we visited the Johnny Hoe river last, and probably pre-spawning movements accounted for the large catches.

The standard errors of the average number of fish caught per set net were: inshore area of open lake  $\pm 0.5$ ; non-marshy bays  $\pm 1.1$ ; marshy bays  $\pm 0.5$ ; river mouths  $\pm 0.8$ ; Johnny Hoe river mouth  $\pm 1.3$ .

The offshore area of the open lake, which comprises about 84% of the total area, was not sampled. Since the main source of food is the shore area and the surrounding land, it is probably sparsely populated.

Aside from cases where spawning runs were involved, the net catches indicated preferred conditions for lake trout in non-marshy bays. Although lake trout were taken in the colder open lake—and in fact were practically the only fish found there—they seemed to be less numerous there. Towards the other extreme, they were also less numerous in the warmer, more turbid river mouths, and least abundant in the marshy bays.

#### GROWTH, MATURITY AND SPAWNING

Our catch comprised a series of trout from those in their first summer to fish over thirty years old. The analysis of the age of these (from their scales) and observations on spawning, habitat and parasites enable us to prepare at least a partial account of their life history.

#### GROWTH RATE

The scales of 366 trout have been examined for age determination. A representative series of 60 was mounted and studied by projection, under high magnification, on a ground glass screen. The remainder were studied dry under binocular microscopes at 65 diameters magnification. A great deal of difficulty was experienced in the interpretation of these scales. We were greatly aided by Dr. Rawson, who sent us a series of mounted scales from trout of lake Minnewanka, Great Slave lake and lake Athabaska. With these and the study of the length frequency distribution of our catch it was possible to determine the ages with reasonable certainty up to about 23 years. Beyond this age we were unable to make the scale interpretation correspond with a reasonable extrapolation of the growth curve. The average lengths and weights of each age group are shown in table I.

From the data in table I two curves have been prepared. Figure 1 shows growth in length and figure 2 growth in weight. All the fish are plotted on both curves with the exception of the two heaviest in figure 2 which were omitted to save space. Both curves represent a smoothed line through the average values for each age group up to 23 years. Beyond this age the curves are visual extrapolations.

The trout grow very slowly; by three years they have reached only a little over three inches (7.6 cm.) and weigh just one ounce (28 g.). They do not reach

a pound (0.45 kg.) until their ninth year, nor two pounds until their fourteenth year. The largest fish, weighing over twenty pounds are more than thirty years old. Just how old they are it is not possible for us to state. By extrapolating the growth curves their ages appear to be up in the fifties but scale examination

TABLE I. The average total lengths (measured to fork of tail) and the average weights (kg. and ounces) for each age group of Great Bear lake trout. Age is number of completed annuli.

Age	No. of fish	Avg. length (cm.)	Average weight (kg.) (oz.)	
0	14	2.8	....	....
1	29	6.3	0.002	0.08
2	10	9.8	0.01	0.4
3	2	13.4	0.028	1.0
4*	1	18.0±	....	....
7	4	29.3	0.40	14
8	4	32.0	0.40	14
9	10	35.4	0.51	18
10	7	37.2	0.58	20
11	14	41.2	0.74	26
12	11	41.2	0.77	27
13	13	42.0	0.82	29
14	17	44.9	0.99	35
15	27	48.7	1.33	48
16	32	51.5	1.61	57
17	33	55.6	1.90	68
18	23	57.4	2.32	82
19	30	60.7	2.64	93
20	22	62.6	2.86	101
21	10	65.6	2.92	103
22	9	70.0	3.60	127
23	10	69.8	3.80	134
24 ?	6	71.9	4.39	140
25 ?	7	76.7	4.85	173
26 ?	8	77.5	5.30	187
27 ?	2	77.9	4.75	168
29 ?	3	79.8	6.25	221
30 ?	3	80.8	6.25	221
31 ?	1	83.7	5.90	208
32 ?	1	93.0	10.9	384
33 ?	1	90.8	5.90	208
35 ?	1	84.3	7.25	256
37 ?	1	96.5	15.4	544

\*Fish taken from stomach of a pike.

does not confirm this. It is possible that this discrepancy is the result of differential mortality; the faster-growing fish may live longer than the slower-growing ones. Consequently, the oldest and largest fish are younger, for their size, than the general average of the population.

The black dots on the curves represent mature males and females; males are distinguished by an arrow on the dot. A study of the distribution of these dots on the curves does not reveal any significant difference in the rate of growth of males and females either in length or in weight. The great uncertainty in the age determination from the scales does not warrant a precise mathematical evaluation of the comparative rates of growth of males and females.

As mentioned above, Dr. Rawson has kindly allowed us to examine his unpublished trout data for lake Minnewanka and for Great Slave lake. The Great Bear lake trout grow more slowly than the Minnewanka trout in their

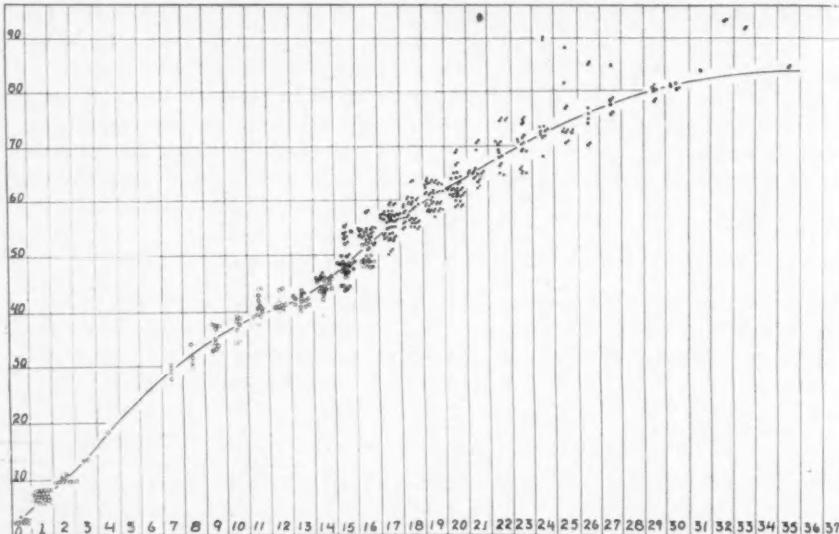


FIGURE 1. The rate of growth in length of the lake trout of Great Bear lake. The ordinates are total lengths in cm.; the abscissae are ages in years. Open circles represent immature fish; closed circles with arrows are mature males and without arrows are mature females.

earlier years. The difference in growth rate diminishes with age until, at age 16, curves of the two populations cross each other. From 16 years on the Great Bear trout appear to grow faster. This is again possibly due to differential mortality between the faster and slower growing individuals.

The Great Slave lake trout grow faster than the Great Bear trout until age 22; at that age the growth curves cross. This is possibly due to faulty age determination of the larger trout.

According to Van Oosten (1943) lake Michigan trout grow very nearly twice as fast, and, from a few fish, it appears that lake Superior trout also grow almost twice as rapidly.

#### MATURITY

In figures 1 and 2 the open circles represent immature fish and the solid circles mature fish. The first mature fish appear at age 13; the proportion of

mature fish increases each year thereafter until, at age 17, all the fish are mature. The youngest mature fish are 42 cm. long (16.5 in.) and weigh 0.85 kg. (about 2 lb.). The most striking fact brought out by these curves is the change in growth rate at sexual maturity. The fish grow more slowly in length from ages 12 to 14, the time at which their gonads are maturing; from 15 years on the growth rate speeds up to about the same rate as before maturity. Growth in weight is very slow until maturity; from age 15 on the curve of growth in weight ascends much more steeply.

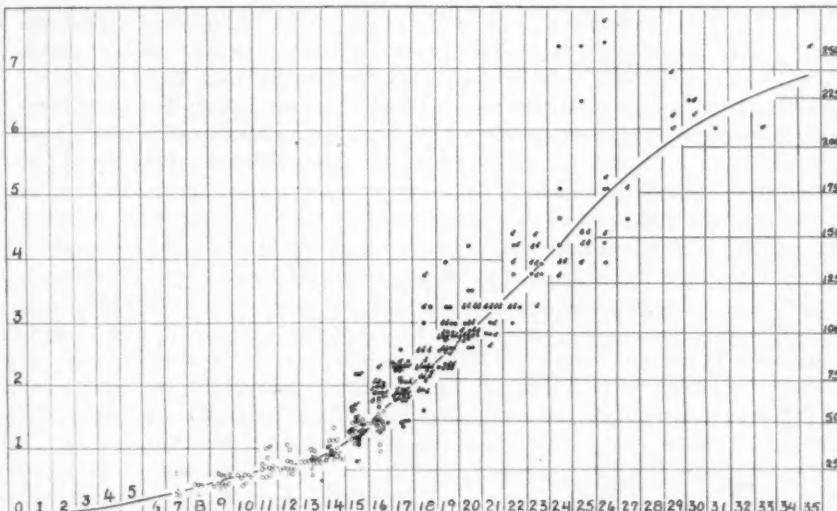


FIGURE 2. The rate of growth in weight of the lake trout of Great Bear lake. The ordinates on the left are kilograms; those on the right are ounces; the abscissae are ages in years. Open circles represent immature fish; closed circles with arrows are mature males and without arrows are mature females.

There appears to be no difference between males and females in the age of attaining maturity.

In lake Michigan Van Oosten (1943) reports that lake trout reach sexual maturity at seven years.

#### TIME OF SPAWNING

Spawning begins quite early in the summer. On August 14 we set our nets in a spawning run on the west shore. The fish were moving close in to shore over a sand and boulder bottom from ten to twenty feet deep. Our sample of 92 contained 75 male, 12 female and 5 immature fish. Evidently the males move onto the spawning grounds before the females. Spawning had just begun as only 8 of the males and 2 of the females were spent. The remainder of the mature fish were ripe and obviously in spawning condition. Sixty of the spawning fish had

empty stomachs, and the others had nearly empty stomachs (grasshoppers, sculpin).

The mature fish of this spawning run were pretty much of a size; the average weight was 5.2 pounds. Unfortunately, scales were taken from only a few of these fish, but, from the growth curve (fig. 2) the age of a five-pound fish is seen to be from 17 to 19 years. As might be expected, this early spawning run was composed of the younger mature fish.

We observed no other spawning runs so the duration of the spawning period is not known.

#### FREQUENCY OF SPAWNING

Soon after we began examining trout in the field we noticed that many large fish appeared to be immature, whereas other fish, sometimes smaller, had gonads which were almost ripe. It was not until quite late in the season that we realized these large, apparently immature fish were probably mature trout which would not spawn that season. In other words the trout ordinarily do not spawn every season. After this conclusion we began to record the state of the gonads very carefully. In the case of males a gross examination of the testes is not sufficient to give accurate information as to sexual state; but in the females the developing eggs are easily seen. The following figures are our findings: mature females—5 will spawn, 31 will not. Since only 36 females were carefully recorded the findings are not conclusive. A better picture can perhaps be provided by including some of the observations made previous to the time careful records were kept. The scale envelopes of many large females bear the notation "female, immature?" We feel that these females were really mature fish which were not going to spawn that season. There were 51 females in this category and 42 which were marked mature. Adding these to the figures quoted above the following data are obtained:

	Spawners	Non-spawners
Carefully recorded . . . . .	5	31
Recorded only as female, immature?		
or female, mature . . . . .	42	51
	—	—
Total . . . . .	47	82

From these figures we conclude that the lake trout of Great Bear lake probably spawn only every third year, at most every second year. That is, only one-third to one-half of the mature population spawns in any one year. The division into spawners and non-spawners is probably by age-groups; thus the 17-year-olds appeared to be non-spawners as 13 of 18 females of this age were classified as non-spawners. The 19-year-olds appeared to be spawners, as 16 of 17 females of this age were classified as spawners. Samples of other age groups are too small to give reliable information, although the 16-year-olds with 8 out of 9 females with small ovaries appear to be non-spawners, and the 20-year-olds with 6 out of 10 with large ovaries are possibly spawners.

## THE YOUNG

The fry had hatched by the time the party arrived at Port Radium on June 22. They were observed in large numbers all along the rocky shores of bays; here they lived in crevices in the boulder bottom in only a few inches of water. They seemed to seek the warmest water; one rock pool, about one yard (0.9 m.) square and only three inches deep, contained 26 fry. The average length of the fry was slightly over an inch (2.8 cm.).

Living with the fry, but occurring also in a little deeper water, were one-, two- and three-year-old trout; the first four summers of life are spent in this shallow boulder habitat in company with sculpins and sticklebacks. Four-, five- and six-year-olds were not seen inshore, nor were they taken in our nets as our smallest mesh (2½ inch) was too large for them. But we have presented evidence in another section of this paper (Parasites) that the trout, even when adults, do not leave the vicinity of the bay where they were hatched.

## FOOD

The stomachs of most of the trout were examined; no quantitative measurements of the contents were made but their nature was noted and also whether the stomachs were full, half-full, quarter-full, nearly empty or empty. Altogether, 383 stomachs were examined of which 144 were completely empty. In table II

TABLE II. Numbers of individuals among 383 lake trout of various sizes, in which the different food items are found.

Food item	Size of fish			
	Less than 2 lb.	2 to 5 lb.	Over 5 lb.	Total
Caddis larvae.....	11	15	6	32
Stonefly nymphs.....	2	4	1	7
Other aquatic insects.....	3	6	1	10
Amphipods (principally <i>Pontoporeia</i> ).....	2	7	0	9
Molluscs.....	0	2	0	2
Terrestrial insects (flying ants and grass-hoppers).....	8	30	42	80
<i>Mysis relicta</i> .....	8	7	4	19
Plankton.....	13	17	3	33
<i>Cottus cognatus</i> .....	9	14	2	25
Ciscoes, <i>L. artedi</i> (LeSueur).....	7	9	16	32
Sticklebacks, <i>P. pungitius</i> (Linnaeus).....	1	6	2	9
Pike ( <i>E. lucius</i> L.), grayling ( <i>T. signifer</i> Richardson), trout, burbot ( <i>L. lota maculosa</i> (LeSueur), trout perch ( <i>P. omisco-maycus</i> (Walbaum)), coregonines.....	7	15	18	40
Gravel and trash.....	4	4	7	15
Mice.....	0	3	0	3
Empty.....	9	42	93	144

the food items and the number of stomachs in which each occurred are listed. The data are broken into three groups according to the size of trout in order to reveal any change in diet with increasing size.

The data in table II can be more easily comprehended in table III where they are shown concentrated into the principal food groups and expressed as percentages.

TABLE III. The percentage occurrence of the principal food items in stomachs of small, medium and large trout.

Food item	Percentage of stomachs			
	Small trout (less than 2 lb.)	Medium trout (2-5 lb.)	Large trout (over 5 lb.)	Total
Bottom organisms.....	33.9	38.6	8.2	25.1
Plankton.....	39	27.3	7.2	21.8
Terrestrial insects.....	14.8	34.1	43.3	33.5
Fish.....	44.4	50	39.2	44.3

To us the most surprising fact in this analysis is that fish occurred less than half as often as other items in the diet; plankton, insects and bottom organisms occurred more frequently than fish. In small and medium trout bottom organisms and plankton were eaten more often than in larger trout. Fish occurred as often in small trout as in large. The surface-feeding habit is apparently better developed in large trout as the frequency of terrestrial insects in the stomachs definitely increases with size. In lake Michigan (Van Oosten and Deason 1938) lake trout larger than 18 inches in length seldom consumed invertebrates, and fish occurred in 93.4 per cent of all trout stomachs examined. Fry and Kennedy (1937) found the lake trout of lake Opeongo, Ontario, were consuming mainly a fish diet made up of whitefish and yellow perch. Of 105 lake trout from lake Nipigon only one was found to have eaten invertebrates. All the others had consumed fish, mostly ciscoes (Clemens *et al.* 1923, and Clemens, Dymond and Bigelow 1924). Dymond (1928) found that in lake Ontario the trout fed exclusively on fish, principally alewives and ciscoes.

#### FLESH COLOUR

It is well known that the flesh colour of the salmonid fishes is highly variable, even within a single species in one habitat. The lake trout of Great Bear lake varied in flesh colour from pale yellow (almost white) to rich, blood red. We were struck with this variation and our inability to predict, from the external appearance of a trout, the probable colour of its flesh. Finally we began to record flesh colour according to a simple scale: 1, white to pale yellow; 2, yellow; 3, orange to pink; and 4, red. Each of 73 trout was assigned a position in this colour scale. The data collected in this way are shown in table IV, arranged first, according to size, then according to sex, and finally according to sexual condition (spawners and non-spawners).

An examination of table IV shows clearly that flesh colour is related neither to size nor sex. Small and large trout are equally likely to have pale flesh or coloured flesh; males and females show no tendency to differ significantly in flesh colour. When the flesh colour data are arranged according to sexual condition,

TABLE IV. Percentage of trout having flesh colour of each of four grades shown in relation to size, sex and sexual condition. Small trout—less than two feet total length; large trout—greater than two feet total length.

	Colour			
	1	2	3	4
Small trout.....	16.6	25.0	50	8.4
Large trout.....	16.6	39	44.0	0
Males.....	29	38.7	29	3.3
Females.....	25.6	28.2	41	5.2
Spawners.....	51.8	38	10.2	0
Non-spawners.....	9.8	29.3	53.7	7.2

however, a very significant association appears. Fish preparing to spawn are almost 90% white or yellow fleshed; fish which are not preparing to spawn are over 60% orange or red fleshed, and only 39% pale fleshed.

From these data we have concluded that in Great Bear lake trout flesh colour is definitely associated with the degree of development of the gonads. Probably the developing eggs or sperm use the reserve of fat which gives the flesh its colour.

#### TAXONOMY

Fourteen lake trout whose standard lengths ranged from 270 to 859 millimeters, were used in a taxonomic study, while fresh. The measurements and counts which were taken are shown in table V. These measurements and counts were made as described by Dymond (1943). All the fish were taken in the vicinity of Port Radium. Since they varied considerably in size, proportional measurements have not been calculated.

Since we did not have access to any lake trout from the type locality which is Hudson's bay, we took measurements and counts on six preserved specimens, numbers 10435, 10436, 10437, 10438, 10439 and 10444 from the collection in the Royal Ontario Museum of Zoology from Favourable lake, Ontario. Graphical comparisons of fish from the two lakes in regard to (1) the size of a part for a given length, (2) average counts, indicates that the populations are essentially the same, and that the lake trout of Great Bear lake are therefore typical *Cristivomer namaycush*.

There was some indication that fish numbers 6, 22, 84 and 85 differed slightly from the remainder of the Great Bear lake fish in average head length, caudal

peduncle depth, body depth, body width, anal fin height, pectoral fin length, and in average gill raker count. Fish numbers 84 and 85 were taken from considerably deeper water than the remainder. Since analyses of stomach contents have indicated that deep water fish feed entirely inshore or at the surface, and since the chances of a fish being caught by gill nets is directly related to the distance it moves, it is also possible that the usual habitat of fish numbers 6 and 22 was deep water, and that they had only entered shallow water temporarily to feed. So the apparent small morphological differences may be associated with the depth of the usual habitat.

TABLE V. Measurements in millimetres and counts on fourteen fresh lake trout from Great Bear lake in the vicinity of Port Radium.

	Field Numbers													
	8	71	51	32	53	75	55	76	7	9	6	84	85	22
Approx. depth of capture (ft.).....	40	100	30	30	30	10	30	10	40	70	40	300	300	60
Standard length.....	270	302	339	360	381	438	439	505	515	520	455	685	756	859
Weight (oz.).....	10	13	20	27	24	48	44	72	80	80	41	136	224	284
Weight (kg.).....	2.8	3.7	5.7	7.7	6.8	14	12	20	23	23	12	39	64	81
Vertebrae.....	64	65	63	63	63	64	61	....	....	....	....	....	....	....
Gill-rakers.....	24	22	25	25	26	26	26	23	22	23	19	23	22	17
Branchiostegals.....	12	12	13	13	11	12	13	12	12	12	12	13	12	13
Head length.....	63	71	81	81	90	102	98	116	124	124	117	198	238	236
Head depth.....	37	40	48	49	52	58	61	70	76	72	63	121	133	139
Eye diameter.....	13	14	16	18	18	19	19	22	20	21	19	30	32	41
Snout length.....	15	17	20	21	21	24	24	29	33	35	34	58	74	76
Interorbital width.....	16	17	21	22	24	30	26	37	36	36	30	58	71	72
Maxillary length.....	31	32	41	45	45	52	49	61	65	64	64	111	143	145
Body depth.....	61	58	73	74	79	102	87	119	122	120	89	133	150	180
Body width.....	35	35	36	41	43	48	52	55	62	65	47	58	74	116
Caudal peduncle length.....	33	42	47	47	50	61	64	68	63	65	58	88	....	120
Caudal peduncle depth.....	22	24	29	29	30	38	36	40	41	39	31	46	....	61
Dorsal rays.....	13	12	12	13	14	14	13	13	13	12	13	13	13	13
Dorsal height.....	45	45	55	57	59	63	68	79	87	76	65	105	98	114
Dorsal base.....	29	33	37	41	41	47	46	58	57	51	51	82	82	99
Anal rays.....	12	11	12	13	13	13	11	13	13	12	11	12	12	11
Anal height.....	36	42	49	49	52	69	61	69	87	75	62	87	101	112
Anal base.....	24	25	31	34	31	38	37	44	49	45	36	66	65	79
Pectoral length.....	43	53	62	71	69	79	85	90	114	96	72	125	127	145
Pelvic length.....	34	44	48	50	52	64	62	71	81	74	54	87	103	107
Sex.....		F	F	F	F	F	F	M	M	F	F	M	M	
Age.....	7	9	10	13	11	15	15	16	18	18	....	26	30	32?

Temperature may be the factor involved, since the average temperature of the deep water is higher than the average temperature of shallow water, because the surface water never warms to appreciably more than the maximum density temperature and for most of the year it is below that temperature. It is interesting to note that fish numbers 6, 22, 84 and 85 resembled the Favourable lake fish more than did the others, and that the average temperature of Favourable lake is probably higher than that of Great Bear lake.

#### PARASITES

Certain parasites of fresh water fishes, particularly the tapeworms, *Triaenophorus crassus* and *Diphyllobothrium latum*, are of considerable economic signi-

fidence. For this reason most of the lake trout taken in the survey were examined for parasites. *Diphyllobothrium latum* was not found but *Triaenophorus crassus* was quite common. A complete list of the parasites found is presented in table VI. Only the more important ones are discussed in the text.

TABLE VI. A list of the parasites collected from lake trout of Great Bear lake

Parasite	Location in host	Abundance
Cestoda		
<i>Eubothrium salvelini</i> (Schrank).....	Intestine, caeca	All trout infested
<i>Triaenophorus crassus</i> Forel.....	Plerocercoid encysted in epaxial muscles	(See text)
<i>Proteocephalus</i> n. sp.(?).....	Intestine	Found in one trout
<i>Diphyllobothrium</i> sp.....	Plerocercoid encysted in visceral peritoneum	Common
Nematoda		
<i>Cystidicola stigmatura</i> (Leidy) Ward and Magath.....	Air bladder	Abundant (see text)
<i>Philonema</i> sp.....	Coelom	Found in five trout
Acanthocephala		
<i>Echinorhynchus salvelini</i> Linkins.....	Stomach, intestine, scales	Abundant (see text)
<i>Echinorhynchus coregoni</i> Linkins.....	Parietal peritoneum	Rare
Copepoda		
<i>Salmincola siscowet</i> (Smith).....	Gills, dorsal and caudal fins	Common (see text)
Hirudinea		
* <i>Piscicola milneri</i> (Verrill).....	Scales, temporary	Fairly common

\*Identified for us by Dr. J. Percy Moore, University of Pennsylvania.

*Triaenophorus crassus* Forel. This tapeworm is the most important parasite of Great Bear lake trout. It occurs as a plerocercoid encysted in the muscles chiefly between the head and dorsal fin, above the lateral line. Three hundred and thirteen trout were cut up in a search for these cysts. The findings, arranged according to locality are shown in table VII.

Table VII shows that the infestation is widespread. It was quite light in most places, but very severe in one locality, Conjuror bay, and fairly severe in another, Richardson island. One Conjuror bay trout had 32 cysts in its flesh. This particular fish was caught by hand; it was flopping around on the surface as if in distress. Nothing unusual about the fish was discovered except the large number of tapeworm cysts. We secured other evidence of these cysts affecting the trout. In the Bear river about one-third of the fingerling lake trout, probably one-year-olds, which we observed had one or two conspicuous bulges on their backs. These bulges interfered very noticeably with swimming. The bulges were found to be due to cysts of *Triaenophorus crassus*.

The data in table VII make a significant contribution to our knowledge of the ecology of lake trout in Great Bear lake. The south end of Richardson island and Gunbarrel inlet are only eight miles apart; yet the Gunbarrel trout are free of this parasite and the Richardson trout 64% infested. Since it has been shown (Miller 1945) that these cysts remain in the flesh of ciscoes for three or four years it is possible to conclude that the trout populations of these two localities, close together though they be, do not mix, but spend their lives each in their natal bay. Similar evidence is given by the figures for Port Radium and Echo bay, separated by only four miles, and Bear point and McVicar arm, separated by about fifty miles.

Tagging experiments on lake trout in lake Michigan (Smith and Van Oosten 1940) showed that the majority of tagged trout was recaptured within 25 miles of the point of release. However, many lake Michigan trout travelled much greater distances, up to 225 miles from point of release. Lake Superior tagging experiments (Van Oosten 1943) also indicated wide ranging of trout in that lake.

TABLE VII. The cysts of *Triadenophorus crassus* in the flesh of lake trout from various localities in Great Bear lake. Averages in last two columns are for the whole sample—both infested and non-infested fish.

Locality	No. of fish examined	No. of fish infested	% infested	No. of cysts	Av. no. /fish	Av. no. /100 lb.
Port Radium.....	73	6	8.2	7	0.1	2.8
Echo bay.....	29	7	24.1	11	0.4	7.8
Lindsley bay.....	27	3	11.1	3	0.1	2.0
Conjuror bay.....	34	31	91.2	207	0.1	92.0
Richardson Island.....	25	16	64.0	63	2.5	36.2
Gunbarrel inlet.....	8	0	0	0	0	0
Fort Franklin.....	53	3	5.7	5	0.1	1.9
Douglas bay .....	19	0	0	0	0	0
Smith arm.....	24	5	20.8	11	0.5	11.2
Bear point.....	8	0	0	0	0	0
McVicar arm.....	13	13	100	23	2.5	37.1
	313	84	26.8	340	1.1	21.5

*Cystidicola stigmatura* (Leidy) Ward and Magath. This nematode was found in immense numbers in the swim bladders of nearly all the trout examined. No evidence of harmful effects was observed. Counts were not made but the large trout often contained a solid half-pint (285 cc.) of these nematodes.

*Echinorhynchus salvelini* Linkins. Most of the trout were infested with this acanthocephalan. They were found not only in the gut but also attached to the scales on the outside of the body. In several trout some of these acanthocephalans were attached to cestodes (*Eubothrium salvelini*) in the intestine.

*Salmincola siscowet* (Smith)? This copepod was common on the gills and the fins of the trout. It can be only provisionally regarded as *S. siscowet* as it does not agree fully with Wilson's description of this species (Wilson 1915). Of

90 trout examined for this parasite, 41 were infested with a total of 85 individuals. The majority were located on the gills; one was found on the caudal fin and one on the dorsal fin.

#### ACKNOWLEDGMENTS

We are very much indebted to Dr. D. S. Rawson, Professor of Biology at the University of Saskatchewan, who allowed us to examine his unpublished data and observations on lake trout from several lakes; this material we found an invaluable aid in the interpretation of the lake trout scales. We also wish to thank Mr. M. B. Smith, a student at the University of British Columbia, who was the third member of our party and the patient recorder of much of our data.

#### REFERENCES

- CLEMENS, W. A., J. R. DYMOND, N. K. BIGELOW, F. B. ADAMSTONE AND W. J. K. HARNES. The food of lake Nipigon fishes. *Univ. Toronto Stud., Biol. Ser. 22. Pub. Ont. Fish. Res. Lab.*, **16**, 171-188, 1923.
- CLEMENS, W. A., J. R. DYMOND, AND N. K. BIGELOW. Food studies of lake Nipigon fishes. *Univ. Toronto Stud., Biol. Ser. 25. Pub. Ont. Fish. Res. Lab.*, **25**, 101-165, 1924.
- DYMOND, J. R. Some factors affecting the production of lake trout (*Cristivomer namaycush*) in lake Ontario. *Univ. Toronto Stud., Biol. Ser. 31. Pub. Ont. Fish. Res. Lab.*, **33**, 27-41, 1928.
- The coregonine fishes of northwestern Canada. *Trans. Roy. Canad. Inst.*, **24**, (II), 171-231, 1943.
- FRY, F. E. J., AND W. A. KENNEDY. Report on the 1936 lake trout investigation, lake Opeongo, Ontario. *Univ. Toronto Stud., Biol. Ser. 42. Pub. Ont. Fish. Res. Lab.*, **54**; 1-20, 1937.
- MILLER, R. B. Studies on cestodes of the genus *Triaenophorus* from fish of Lesser Slave lake, Alberta. IV. The life of *Triaenophorus crassus* Forel in the second intermediate host. *Can. J. Res.*, **D23**, 105-115, 1945.
- SMITH, O. H., AND JOHN VAN OOSTEN. Tagging experiments with lake trout, whitefish and other species of fish from lake Michigan. *Trans. Amer. Fish. Soc.*, **69**, 63-84, 1940.
- VAN OOSTEN, JOHN, AND H. J. DEASON. The food of the lake trout (*Cristivomer namaycush namaycush*) and of the lawyer (*Lota maculosa*) of lake Michigan. *Trans. Amer. Fish. Soc.*, **67**, 155-177, 1938.
- VAN OOSTEN, JOHN. Lake trout. *U.S. Dept. Inter. Fish Wildlife Serv. Fish leaflets*, **15**, 1-8, 1943.
- WILSON, C. B. North American parasitic copepods belonging to the Lernaeopodidae, with a revision of the entire family. *Proc. U.S. Nat. Mus.*, **47**, 565-729, 1915.

## Pike (*Esox lucius*) from Four Northern Canadian Lakes

By R. B. MILLER

*University of Alberta, Edmonton, Alberta*

AND

W. A. KENNEDY

*Central Fisheries Experimental Station, Winnipeg, Man.*

(Received for publication May 31, 1947)

### ABSTRACT

Scale samples and length and weight measurements of 281 pike from Great Bear lake, Great Slave lake, lake Athabaska and Lesser Slave lake have been used to calculate the rate of growth. A comparison with the growth rate of pike from Waskesiu lake, Saskatchewan, and lakes in Wisconsin shows that, in general, the rate varies with north latitude. The northern fish live five years longer but never attain as large a size. It is shown that the relationship between length and weight is independent of the rate of growth. Males and females grow at the same rate but females appear to live longer than males.

During the summer of 1945 the authors carried out a survey of the fisheries of Great Bear lake for the Fisheries Research Board of Canada. In the course of this work 79 great northern pike were examined. In 1941 one of us (R.B.M.) studied 64 pike from Lesser Slave lake, Alberta. We are greatly indebted to Dr. D. S. Rawson, of the University of Saskatchewan, who has given us his measurements and scale samples from 65 pike of lake Athabaska and 73 pike of Great Slave lake. These data are used in this paper for a study of the growth of the pike in northern and far northern waters.

The lakes are all part of the Mackenzie drainage. Lesser Slave, the southernmost, with an area of 462 square miles (1 sq. mi. = 2.6 sq. km.) drains by the Lesser Slave river into the Athabaska river. The Athabaska river flows north into lake Athabaska which has an area of 3,050 square miles. Lake Athabaska drains by the Slave river into Great Slave lake (area of 10,500 square miles). From Great Slave lake the Mackenzie river runs north to the Arctic. Great Bear lake (area of 11,800 square miles) is the farthest north; it lies partially across the Arctic circle.

The small numbers of pike studied from the three large lakes are, of course, inadequate to provide more than an indication of growth rates. The samples

are reasonably representative, however, as they were made up of individuals from widely scattered localities in the lakes.

#### METHODS

Throughout this paper we have used total length (fork length) determined to the nearest millimetre. Weights were recorded to the nearest ounce. Scale samples from each of 281 pike were taken from between the lateral line and the mid-dorsal line, toward the head region. At least two scales from each fish were cleaned and mounted in glycerine jelly. The images of the mounted scales were then projected on cards and the positions of the annuli marked in pencil. Most of the scales were projected to give a magnification of 23, but one lot was magnified 25 diameters.

The length of each pike at the end of each year of its life was calculated from the marks on the cards by a method essentially the same as the one described by Fry (1943); the method was modified according to a suggestion by Fry (personal communication to W.A.K.). The modification eliminates the apparatus used in Fry's original method.

The marks on the cards were converted to actual diameters in mm. by the use of a suitable scale. For instance, where the magnification was 25 times, a straight line on a sheet of paper was marked off at 25 mm. intervals which were subdivided into 10 equal parts. Then each of these intervals, in terms of the markings on the cards, represented one mm. on an unmagnified pike scale, so that it was possible to convert the markings on the cards to scale diameters very easily.

The scale diameter vs. total length relationship of individual fish was plotted for each of the four lakes. Since the distribution of these points did not vary appreciably from graph to graph, the fish in each of the four lakes are assumed to be similar in this relationship. Furthermore, the trend of these points indicated that the pike in these lakes had scales of zero diameter when the fish were about 50 mm. long. Fixing the size at which scales first had an appreciable diameter was greatly facilitated by the fact that nine of the pike from Great Bear lake were between 70 and 100 mm. long. Further, two pike were available from The Pas region in Manitoba which were respectively 29 and 33 mm. long and which had no apparent scales.

When the logarithms of scale diameters were plotted against the logarithms of total length in mm. less 50, the points tended to fall along a straight line, and, further, they tended to fit a straight line better than if logarithms of scale diameters were plotted against the logarithms of total length in mm. less any value other than 50. Actually, instead of plotting the logarithms of the values on arithmetic graph paper, the arithmetic values were plotted on log-log graph paper. It is assumed that scales began to grow when the fish were about 50 mm. long, and that the best straight line through the points which resulted when scale diameters were plotted against total lengths minus 50 on log-log paper represents the way in which a scale on a typical pike increases in diameter as the fish increases in length. This best straight line passes through the points: scale

diameter = 1.0 mm. and total length minus 50 = 60 mm.; and scale diameter = 10.0 mm. and body length minus 50 = 1,000 mm.

This typical line was used in the required calculations in the following way. First, the values given along the X axis of the graph were changed so that they read directly in terms of total length instead of in terms of total length less 50. For example, the ordinate on the log-log graph, designated as 100 mm. when referring to total length less 50, was changed to 150 mm. in terms of body length. Next, for any given fish the scale diameter and total length were noted, the corresponding point was found on the graph, and a straight edge was laid on the graph through the point and parallel to the line representing the typical increase of scale diameter with total length. Then for each scale diameter represented by an annulus, a corresponding total length was read off from the graph along the straight edge and recorded.

The method assumes that any difference in size between an observed scale and a typical scale for a fish of the same length is entirely the result of difference in size at which growth of the scale started, and that increase in size of scale is always at the same rate relative to increase in length of fish.

Fry's method of calculation was used by Kennedy (1943) for whitefish; his lengths at the end of each year of life calculated from young fish were no greater than when older fish were used; i.e., "Lee's phenomenon" (Lee 1912) did not show up. Reference to our tables I-IV shows that, with the exception of Lesser Slave lake, "Lee's phenomenon" does not appear in our data. [In Lesser Slave lake all the pike were taken in one size of gill net (4½ in. stretched measure) so that selection of the faster growing fish of the younger age groups took place (1 in. = 2.54 cm.). In the other lakes graded gangs of gill nets were used and this selection was avoided.] We conclude that, for whitefish and pike, "Lee's

TABLE I. The average calculated total length (mm.) at the end of each year of life and the average calculated weights (oz.) for 70 pike from Great Bear lake (1 oz. equals 28.35 g.).

Age at capture	Frequency	Age groups																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
4	8	100	175	264	333	411													
5	11	94	155	244	334	411													
6	14	97	159	234	319	388	453												
7	7	94	142	234	310	396	470	521											
8	11	92	154	235	316	386	449	510	556										
9	5	86	138	210	281	356	432	500	566	606									
10	5	90	136	205	296	392	468	532	594	636	664								
11	1	85	117	165	232	330	440	520	610	670	740	760							
12	1	88	138	210	290	360	400	440	480	550	600	640	690						
13	2	105	145	217	310	385	440	510	565	610	665	725	765	785					
14	2	100	161	258	330	395	450	500	555	600	645	700	740	780	815				
15	1	90	132	194	245	300	340	400	510	560	610	650	700	750	780	810			
17	1	90	130	200	285	360	440	510	550	590	640	700	750	780	810	840	890	930	
18	1	109	163	260	320	410	470	530	590	640	670	710	740	790	830	870	900	930	950
Grand average.....		95	153	234	314	388	450	509	563	613	657	701	736	764	810	840	895	930	950
Aver. weight (oz.)		2	5	7	10	16	23	32	45	60	73	90	110	118	145	160	195	225	245

TABLE II. The average calculated total length (mm.) at the end of each year of life and the average calculated weights (oz.) of 73 pike from Great Slave lake (1 oz. equals 28.35 g.).

Age at capture	Frequency	Age groups																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2	3	105	159															
3	3	109	171	223														
4	5	106	157	225	289													
5	4	119	183	250	314	368												
6	7	105	177	232	296	341	393											
7	6	105	154	203	261	320	377	420										
8	8	108	162	226	266	353	411	460	501									
9	7	104	156	219	284	346	407	453	497	541								
10	14	104	152	215	279	334	394	451	505	548	582							
11	6	111	163	214	271	323	367	423	462	515	555	595						
12	5	96	144	207	269	334	404	464	512	556	596	634	664					
13	2	100	169	219	268	295	350	395	450	500	545	595	640	675				
14	2	110	151	206	264	325	405	470	505	565	610	650	690	725	750			
17	1	111	169	220	285	340	400	450	490	540	610	680	730	780	820	850	890	920
Grand average.....		106	160	219	282	337	393	445	497	541	579	619	671	716	773	850	890	920
Average weight .....		1?	2?	3	6	9	14	20	28	37	46	53	72	87	112	150	167	185

TABLE III. The average calculated total length (mm.) at the end of each year of life and the average calculated weight (oz.) of 65 pike from lake Athabasca (1 oz. = 28.35 g.).

Age at capture	Frequency	Age groups																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
3	1	94	152	232																					
4	5	113	198	286	346																				
5	5	97	147	223	314	380																			
6	2	97	164	258	320	380	445																		
7	5	102	166	222	296	372	442	494																	
8	7	101	149	228	295	366	436	500	561																
9	6	94	154	217	240	352	418	485	545	592															
10	7	95	150	209	274	336	399	459	526	579	624														
11	6	93	146	214	289	353	415	473	527	585	628	663													
12	7	102	145	216	278	339	407	474	533	590	651	703	746												
13	2	95	143	180	241	313	393	440	520	590	655	720	770	810											
14	3	98	143	210	279	352	422	491	557	613	663	707	760	813	847										
15	1	108	163	233	305	390	460	520	590	650	710	750	810	860	900	930									
16	1	92	133	190	240	300	380	450	520	570	610	650	700	730	780	830	890								
17	1	128	164	202	270	325	380	440	500	560	620	700	730	760	820	860	900	920							
18	2	98	145	200	320	325	385	455	510	570	615	665	705	765	815	865	915	960	1000						
19	1	91	132	183	225	290	350	400	450	490	560	610	670	740	780	810	870	900	940	980					
20	1	112	145	220	270	310	400	460	500	560	610	650	710	740	780	820	860	920	950	990	1050				
23	1	105	142	198	250	310	370	410	450	470	520	580	640	680	720	770	810	850	910	960	1020	1050	1070	1120	
24	1	111	174	240	300	380	480	520	580	620	650	690	730	760	800	830	860	900	940	990	1030	1060	1090	1140	1160
Grand aver.		100	154	222	290	350	415	476	534	583	633	683	735	776	813	842	878	916	957	980	1043	1055	1080	1130	1160
Aver. weight		1	2	3	7	10	18	22	38	52	65	84	102	122	140	155	180	205	250	275	350	370	395	500	.....

TABLE IV. The average calculated total lengths (mm.) at the end of each year of life of 64 pike from Lesser Slave lake

Age at capture	Frequency	Age groups								
		1	2	3	4	5	6	7	8	9
1	1	172								
2	3	176	280							
3	2	167	272	360						
4	21	135	226	315	380					
5	15	132	203	287	350	406				
6	7	138	226	299	377	443	496			
7	8	133	201	284	369	436	494	534		
8	5	137	196	270	348	414	482	536	574	
9	2	121	192	271	350	425	495	550	610	645
Grand average..... (4-9 year-old* only)		135	212	296	367	422	492	537	584	645

phenomenon" probably is an artefact introduced by inaccurate methods of growth computation.

The weights at the end of each year of life were determined by plotting the observed lengths vs. the observed weights for each lake. The resulting curves were then used to find the weight for the average calculated total length at the end of each year of life.

#### RATE OF GROWTH LENGTH

The calculated lengths at the end of each year of life and the grand average calculated lengths are shown in tables I to IV, and graphically in figure 1. Also shown on figure 1 are Van Engel's data (1940) for pike in Wisconsin lakes and Rawson's data (1932) for the pike of Waskesiu lake, Saskatchewan.

With the exception of Great Bear lake the rate of growth in length varies inversely with north latitude. Between ages three and twelve the relative growth rates are shown in the following tabulation, in which the lakes are arranged in the order of growth rate of the pike, slowest given first:

Lake	°N. Lat.	Weeks of ice cover	Max. summer	Altitude	Source of data
			°F. (°C.)		
Great Slave.....	62	35	45-55 (7-13)	520 (158)	Rawson 1947
Athabaska.....	59	35	60-66 (15.5-19)	695 (212)	Rawson 1947
Great Bear.....	66	35	51 (10.6)	391 (119)	Miller 1947
Lesser Slave....	55	26	71 (21.7)	1,892 (577)	Miller 1941 (unpub.)
Waskesiu.....	53	26	68 (20)	1,740 (531)	Rawson 1936
Wisconsin..... (Lake Mendota)	43	12-16	75.6 (24.2)	850 (259)	Juday 1940

This shows that the growth rate increases with decreasing latitude except for Great Bear lake, whose pike should have the slowest growth rate but actually grow faster than Athabaska and Great Slave pike. This difference may be apparent rather than real. An examination of figure 1 shows that, in the first

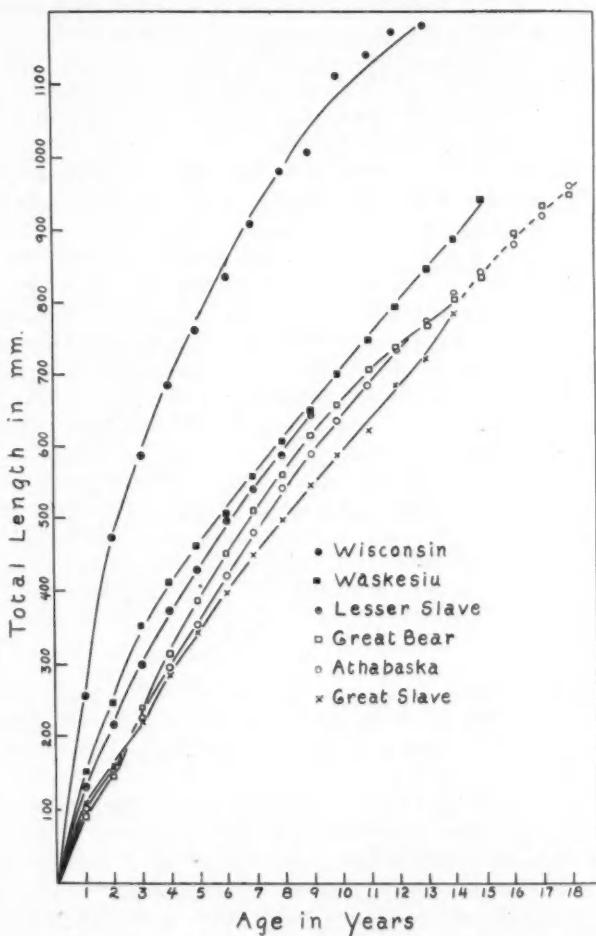


FIGURE 1. Rate of growth in length of the northern pike. (Data for Waskesiu are lengths at time of capture.)

two years, the Great Bear pike actually are smaller than in the other two lakes. Further, at age 14, the growth rates of the pike of the three northernmost lakes appear to become the same. Probably the best conclusion is that there is no great difference in the growth rates of the pike of these three lakes, and that the observed differences are due mainly to experimental error involved in dealing

with rather small samples of the populations. This is reasonable in view of the similar periods of ice cover and the probably very similar summer conditions in the shallower bays where pike choose to live.

The curves in figure 1 draw attention to the vast variation in growth potential which the pike possesses. Thus, in Wisconsin, a pike reaches in three years a slightly greater length than is achieved in ten years in Great Slave lake.

The enormously increased growth rate in southern waters is associated with a decrease in length of life. The maximum age group of pike from Wisconsin waters was 14 years; few were found older than 9 years. In the present study the oldest pike was found in lake Athabaska at age 24, i.e., in its twentyfifth year. In Great Slave the oldest was in its eighteenth year and in Great Bear in its nineteenth year. In the three northern lakes as a whole, 13 pike (about 6 %), were older than 14; in Wisconsin, less than 4 % were older than 9. At the slower growth rate the life is increased, therefore, at least five years.

The possible effects of different fishing mortalities in the various lakes have not been considered in this discussion as we have no data which would enable us to evaluate them. That such effects are not influencing the findings appreciably seems fairly certain, since we found the oldest pike in lake Athabaska, a lake which has supported a commercial fishery for many years, whereas there is no commercial fishery in Great Bear lake and in Great Slave lake commercial fishing began only in 1945.

The longer life of the northern fish does not fully compensate for the slower rate of growth as the southern pike reach considerably greater sizes. It is interesting to note that this is not true in the case of the Arctic grayling where it has been shown (Miller 1946) that the northern fish not only live longer but reach a much greater size than the southern fish.

#### WEIGHT

The calculated weights at the end of each year of life for pike of the three large lakes (tables I, II and III) bring out nothing new in comparative growth rates. They show that increase in weight is faster after the first seven or eight years.

The relationship between length and weight in the three northernmost lakes and in the Wisconsin lakes is shown graphically in figure 2. The curves show that the length-weight relationship is scarcely changed by varying rates of growth, but is, presumably, characteristic for the species at any growth rate. If the same data are plotted on log-log paper, four very closely approximated, parallel, straight lines result. The slope of these lines is 3.17; this indicates a relationship, constant at any latitude, of weight varying as the 3.17 power of the length.

#### MALES AND FEMALES

Table V shows the calculated lengths of males and females for each year of life in lakes Athabaska, Great Bear and Great Slave, and the grand average

for all three of these lakes. The data reveal no difference in the rate of growth of males and females, although the females appear to live longer and hence attain a larger size (in Athabasca and Great Slave). Rawson (1932) in his sample of Waskesiu lake pike, found no males older than 10 years but did find females up to 16 years old.

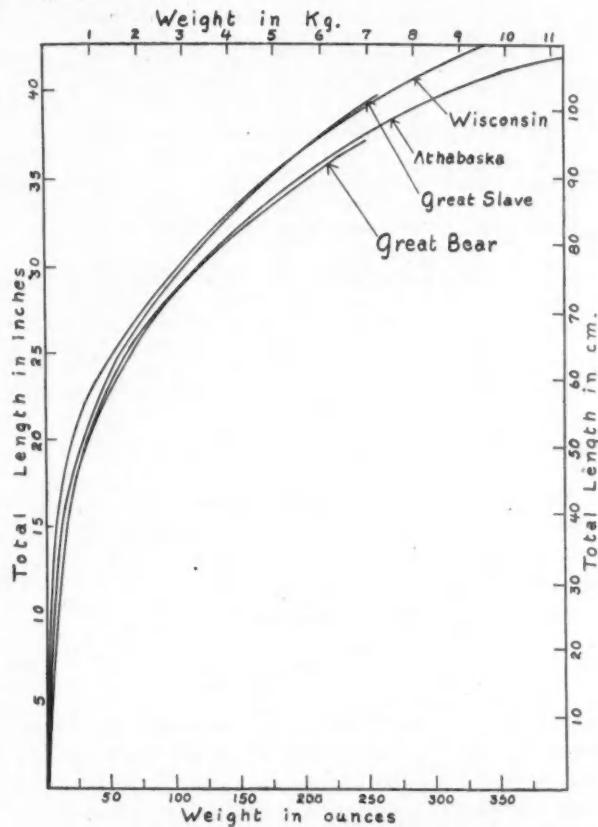


Figure 2. Length-weight relationships of the northern pike.

#### AGE AT MATURITY

We are able to present data on age at maturity for Great Bear lake pike only. In this lake, maturity in the younger age groups was as follows:—

Age group	Number examined	Number immature	Mature males	Mature females
4	8	6	2	..
5	11	4	4	3
6	14	2	7	5
7	7	1	1	5

TABLE V. Average calculated total length (mm.) of male and female pike for each of three lakes and the average for the three lakes.

Age	Athabaska		Great Bear		Great Slave		Average		Total frequency	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1	96	101	93	94	107	105	100	100	83	98
2	151	150	153	160	160	160	155	153	83	98
3	214	216	236	227	217	220	223	221	83	98
4	288	281	318	308	281	282	296	289	82	98
5	297	345	388	387	336	336	342	354	76	97
6	419	412	443	452	388	396	416	419	65	93
7	481	474	458	524	442	449	469	477	51	86
8	537	529	540	579	496	497	524	527	43	77
9	588	580	589	627	540	541	570	573	32	62
10	633	633	626	674	580	579	611	618	21	55
11	688	682	665	730	644	608	666	666	14	36
12	760	735	708	765	690	663	713	721	9	28
13	.....	776	757	795	740	710	753	768	4	21
14	.....	813	790	840	760	780	783	813	4	15
15	.....	842	840	840	.....	850	840	844	2	10
16	.....	878	900	890	.....	890	900	882	1	9
17	.....	916	930	930	.....	920	930	920	1	8
18	.....	960	950	.....	.....	.....	950	960	1	5
19	.....	977	.....	.....	.....	.....	977	.....	3	
20	.....	1035	.....	.....	.....	.....	.....	1035	.....	2
21	.....	1050	.....	.....	.....	.....	.....	1050	.....	1
22	.....	1070	.....	.....	.....	.....	.....	1070	.....	1
23	.....	1120	.....	.....	.....	.....	.....	1120	.....	1

No immature fish older than 7 years were found. From this it appears that males begin maturing in their fifth summer and females in their sixth, but these few data cannot be regarded as conclusive. Rawson (1932) found in Waskesiu lake that some females spawned at the end of their third year and that few, if any, males spawned until the end of their fourth year.

#### SUMMARY

Scale samples and length and weight measurements for 79 great northern pike from Great Bear lake, 73 from Great Slave lake, 65 from Lake Athabaska and 64 (without weight data) from Lesser Slave lake have been studied.

The average calculated total lengths at the end of each year of life are compared to similar data for pike from Wisconsin waters and to lengths at capture of pike from Waskesiu lake, Saskatchewan. In general, the growth rate varies inversely with north latitude. Pike of the three northernmost lakes show very little difference in growth rate. The pike from the northern lakes live at least five years longer than the faster growing southern fish but do not get as large.

"Lee's phenomenon" does not appear in the length calculations, probably by virtue of the method of calculation used; this method is explained.

The relationship between length and weight remains constant irrespective of rate of growth.

Males and females do not grow at significantly different rates in the three northern lakes. Females appear to live longer than males.

Some of the males of Great Bear lake pike mature in their fifth summer and some of the females in their sixth. All fish are mature by their ninth summer.

#### REFERENCES

- FRY, F. E. J. A method for the calculation of the growth of fishes from scale measurements. *Univ. Toronto Stud. Biol. Ser. 51. Pub. Ont. Fish. Res. Lab.*, **61**, 6-18, 1943.
- JUDAY, C. The annual energy budget of an inland lake. *Ecology*, **21** (4), 438-450, 1940.
- KENNEDY, W. A. The whitefish, *Coregonus clupeaformis* (Mitchill), of lake Opeongo, Algonquin Park, Ontario. *Univ. Toronto Stud., Biol. Ser. 51. Pub. Ont. Fish. Res. Lab.*, **62**, 22-66, 1943.
- LEE, R. M. An investigation into the methods of growth determination in fishes. *Pub. Circ. Cons. Explor. Mer.*, **63**, 1-35, 1912.
- MILLER, R. B. Notes on the Arctic grayling, *Thymallus signifer*, Richardson, from Great Bear lake. *Copeia*, **1946** (4), 227-236, 1946.
- North West Canadian fisheries surveys in 1944-45. IV. Great Bear lake. *Bull. Fish. Res. Bd. Can.*, **72**, 31-34, 1947.
- RAWSON, D. S. The pike of Waskesiu lake, Saskatchewan. *Trans. Amer. Fish. Soc.*, **62**, 323-330, 1932.
- Physical and chemical studies in lakes of Prince Albert Park, Saskatchewan. *Jour. Biol. Bd. Can.*, **2** (3), 227-284, 1936.
- North West Canadian fisheries surveys in 1944-45. V. Great Slave lake; VI. Lake Athabaska. *Bull. Fish. Res. Bd. Can.*, **72**, 45-85, 1947.
- VAN ENGEL, W. A. The rate of growth of the northern pike, *Esox lucius* Linnaeus, in Wisconsin waters. *Copeia*, **1940** (3), 177-188, 1940.

## Le Séchage Artificiel du Capelan Frais

PAR H. FOUGÈRE

*Station Expérimentale de Pêche de la Gaspésie  
Grande-Rivière, P.Q.*

(Reçu pour publication le 4 mars, 1947)

### RÉSUMÉ

Le capelan frais peut être séché jusqu'à une teneur en eau de 42% base sèche (30% base humide) en 20 heures, avec un courant d'air d'une vitesse linéaire de 150 cms. à la seconde, à la température de 35°C et à 60% d'humidité relative. Un courant d'air de 250 cms. à la seconde à 26.7°C et de 50% d'humidité relative donne à peu près les mêmes résultats. Le capelan sèche d'autant plus vite qu'il est plus petit; les caractéristiques de séchage du capelan frais et du capelan décongelé sont les mêmes. L'humidité relative optima pour l'entreposage du capelan séché est de 75%. Cette humidité relative correspond à un pourcentage d'eau d'équilibre de 26%.

Le séchage artificiel du poisson n'a été appliqué jusqu'à présent qu'au poisson salé. Les travaux types de ce genre sont ceux de Cooper (1938) sur l'eau d'équilibre dans la chair de morue salée, de Cooper et Wood (1940) et de Linton et Wood (1945) sur les conditions de séchage de la morue fortement salée. Ces travaux ont orienté la marche du présent travail.

Dans l'Est du Canada, le capelan est le seul poisson qui est séché à l'état frais. Il n'a jamais été l'objet d'une étude systématique de séchage artificiel. Il est capturé sur la rive Nord du fleuve Saint-Laurent en quantités considérables, le printemps, et séché sur le rivage le long de la Côte, puis expédié sur le marché comme nourriture pour les animaux à fourrure. Mais, cette région trop souvent brumeuse et relativement froide, ne se prête guère au séchage naturel. Il en résulte un produit peu uniforme et partiellement décomposé.

Le but de ce travail est de déterminer les conditions optima de température, de vitesse de courant d'air et d'humidité relative capables de sécher du capelan frais, jusqu'à concurrence d'environ 41% d'eau, base sèche (30% base humide); d'établir les conditions optima d'entreposage en déterminant l'eau d'équilibre dans le capelan et en suivant le développement des moisissures sur du capelan séché, en fonction de la température et de l'humidité relative. A l'état frais, le capelan peut être considéré comme un système composé de 80% d'eau, de 18% de protéines et 1% de matières grasses.

### MÉTHODE

Les expériences ont consisté à comparer l'effet de diverses conditions de séchage. Ainsi pour obtenir une comparaison convenable, les résultats sont exprimés comme eau résiduelle en pourcentage de l'eau totale,  $\frac{P - H}{P} \times 100$ , où  $P$  = poids d'eau initiale dans l'échantillon,  $H$  = poids d'eau évaporée à un instant donné.

Chaque expérience de séchage a été faite sur un poids de  $45 \pm 3$  grammes de capelan de même taille.

L'appareil employé pour poursuivre la marche du séchage est une adaptation du principe du tunnel, tel qu'employé par Cooper et Wood (1940). La perte de poids du poisson due à l'évaporation de l'eau durant le séchage a été enregistrée par une balance automatique.

L'eau d'équilibre a été déterminée par la méthode de Wink (1946).

Le développement des moisissures a été suivi sur du capelan séché suspendu dans des ballons hermétiquement fermés et contenant des solutions saturées de sels dont les tensions de vapeur sont définies suivant la température. Les humidités relatives correspondant à ces solutions saturées sont données dans le travail de Wink (1946) et dans les "International Critical Tables" (1926).

### SÉCHAGE

Des expériences de séchage ont été effectuées à des températures variant de  $24^{\circ}\text{C}$  ( $75^{\circ}\text{F}$ ) à  $35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ) et à des humidités relatives variant de 50% à 80%, la vitesse du courant d'air étant constante à 150 cms. à la seconde (300 pds. à la minute). Ces expériences ont été faites en trois séries dont la première, considérée comme préliminaire, a permis de juger de l'allure du séchage pour les conditions étudiées pendant une période de 12 heures. Ainsi, la moitié des courbes présentaient des résultats suffisamment favorables. Elles ont donc été répétées deux fois chacune, la durée du séchage étant cette fois de 32 heures. De cette deuxième série, quelques-unes des courbes ont été choisies comme représentant les conditions de séchage les plus favorables.

Les basses températures ont donné des résultats peu pratiques, parce qu'elles exigent des humidités relatives trop faibles et difficiles à obtenir économiquement.

### PETIT ET GROS CAPELAN

En général la longueur du capelan varie entre 8 et 15 centimètres. Afin de déterminer l'influence de la grosseur du capelan sur la vitesse de séchage, des expériences ont été effectuées sur du petit, du moyen et du gros capelan, les conditions de séchage étant les mêmes dans chaque cas.

Selon la figure 1, la vitesse de séchage est inversement proportionnelle à la grosseur.

Ces résultats sont d'accord avec les principes fondamentaux du séchage artificiel (Walker, Lewis et Adams 1927.) Ils sont en outre analogues à ceux de

Linton et Wood (1945) qui ont constaté que la vitesse de séchage de la morue salée est inversement proportionnelle à l'épaisseur. Ils rappellent encore les expériences de Dunlap (1946) qui démontrent que la vitesse de séchage des carottes est inversement proportionnelle à la grosseur des morceaux qui sont

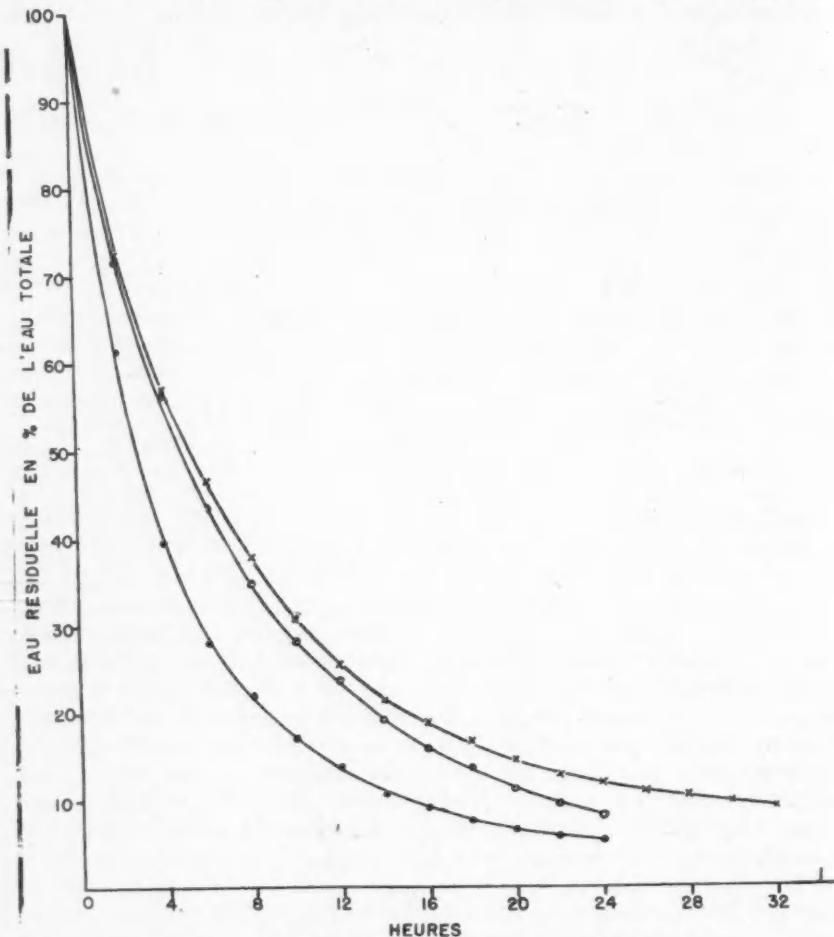


FIGURE 1. Comparaison de l'allure du séchage du capelan de différentes tailles.  
—x— gros; —○— moyen; —●— petit.

soumis au séchage. Ainsi le séchage du capelan frais, au point de vue de vitesse de séchage, semble suivre la règle générale.

Il s'ensuit que dans un mélange de capelan, à un moment donné du séchage, la teneur moyenne en eau devrait varier suivant la prédominance des gros, des moyens ou des petits individus. En pratique, cette variante ne présente aucun inconvenient, à condition toutefois que le gros capelan soit séché jusqu'à con-

currence de la teneur en eau désirée. Pour cette raison, toutes les courbes de séchage ont été faites avec du gros capelan.

### CAPELAN CONGELÉ

La congélation a pour effet de conserver un produit alimentaire jusqu'au moment de la consommation. Dans certains cas toutefois, et surtout lorsqu'il s'agit de la mise en conserve de certains produits de pêche dont la capture est aléatoire, on peut avoir recours à la congélation afin d'accumuler une quantité suffisante de matière première pour assurer l'opération continue d'une usine. Sigurdsson (1945) préconise la conservation du hareng dans la saumure à 0°C ou moins, lorsque la capture excède la capacité de l'usine de mise en conserve. Fieger et DuBois (1946), pour une raison semblable, recommandent soit la congélation, soit l'entreposage des crevettes à 0°C-2°C, jusqu'à ce qu'elles puissent être mises en conserve. Cette pratique toutefois n'est qu'un moindre mal et n'améliore pas la qualité du produit fini. Mais elle permet de réaliser une continuité dans les opérations tout en assurant un produit de bonne qualité.

Ainsi des expériences ont été faites pour vérifier si les caractéristiques de séchage du capelan soumis à la congélation, puis décongelé préalablement au séchage, sont les mêmes que celles du capelan frais. Ces expériences ont un intérêt expérimental et pratique à la fois. Elles ont d'abord été faites pour la recherche de résultats susceptibles de faciliter la poursuite de ce travail sans faire perdre de vue l'intérêt pratique qu'elles peuvent présenter.

TABLEAU I. Comparaison entre l'allure du séchage du capelan frais et décongelé. Courant d'air 150 cms. la seconde.

Heures de séchage.	23.9°C. 62% H.R.		26.7°C. 63% H.R.	
	Congelé	Frais	Congelé	Frais
	Eau résiduelle en % de l'eau totale	Eau résiduelle en % de l'eau totale		
1	93.1	92.8	89.8	90.6
2	86.2	86.9	82.7	83.4
3	80.9	87.2	77.2	77.8
4	76.3	76.6	72.7	72.6
5	72.3	73.0	68.5	68.8
6	69.6	70.3	66.8	65.7
7	66.1	66.9	62.0	62.0
8	63.8	63.8	59.0	59.4
9	61.9	60.9	56.6	56.2
10	59.6	59.0	54.1	53.8
11	56.9	55.8	52.1	51.6
12	55.5	52.5	50.5	47.6

Du capelan frais a été enveloppé, par lots de 5 spécimens, dans du papier ciré, puis soumis à la congélation lente à la température de  $-5^{\circ}\text{C}$ . Il a été maintenu à l'état de congélation pendant une semaine environ, puis ramené à la température du laboratoire avant d'être soumis au séchage. Du capelan frais a aussi été ramené à la température du laboratoire, puis séché aux mêmes conditions.

Deux expériences ont été tentées; l'une à  $23.9^{\circ}\text{C}$  ( $73^{\circ}\text{F}$ ) et 62% d'humidité relative, l'autre à  $26.7^{\circ}\text{C}$  ( $80^{\circ}\text{F}$ ) et 65% d'humidité relative, la vitesse du courant d'air étant constante à 150 cms. à la seconde (300 pds. à la minute). Le tableau I indique que les caractéristiques de séchage du capelan décongelé et frais sont les mêmes.

Nous nous sommes particulièrement appliqués ici à l'étude des effets de la congélation sur la vitesse de séchage, délaissant les autres aspects pour le moment. Bien que l'apparence du produit soit d'ordre secondaire, nous n'avons constaté aucune différence entre le capelan séché soit à partir du capelan décongelé, soit à partir du capelan frais.

A la suite de ces résultats, du capelan frais a été enveloppé en lots de cinq dans du papier ciré, congelé et entreposé en quantité suffisante pour permettre de poursuivre cette étude tout d'un trait, ce qui aurait été impossible autrement, car le capelan n'apparaît sur la côte qu'au moment du printemps, et ceci pendant un mois à peine. Ainsi, toutes nos expériences ont été faites avec du gros capelan décongelé et ramené à la température du laboratoire.

#### TEMPÉRATURE ET HUMIDITÉ RELATIVE

Dans la poursuite de nos expériences de séchage, les températures de  $26.7^{\circ}\text{C}$  ( $80^{\circ}\text{F}$ ),  $32.2^{\circ}\text{C}$  ( $90^{\circ}\text{F}$ ) et  $35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ) et les humidités relatives de 50% et 60% ont été choisies, la vitesse du courant d'air étant d'abord constante à 150 cms. à la seconde (300 pds. à la minute).

Dans la région où se pratique la pêche du capelan l'humidité de l'atmosphère est en général assez élevée, et, pour obvier en autant que possible à la nécessité de dessécher l'air avant de l'introduire dans le séchoir, nous nous sommes limités aux températures ci-haut mentionnées.

Pour effectuer une vitesse de séchage convenable l'humidité relative doit augmenter proportionnellement à la température. Ce fait est mis en évidence dans la figure 2. En outre, la température de  $35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ) ne semble aucunement affecter les tissus conjonctifs du capelan, c'est-à-dire que le poisson n'est pas cuit à cette température élevée. A titre de comparaison, la morue salée ne peut être exposée longtemps à la température de  $26.5^{\circ}\text{C}$  ( $80^{\circ}\text{F}$ ) sans subir une cuisson partielle (Linton et Wood 1945).

Dans la limite des températures choisies, quand l'humidité relative est trop basse, le séchage est rapide au début, puis ralentit promptement par la suite. Le séchage du capelan s'effectue donc plus lentement au fur et à mesure que l'humidité relative diminue. Ce phénomène n'est pas nouveau et a été particulièrement observé dans le séchage de la morue salée. Il s'explique par le fait que la vitesse d'évaporation est beaucoup plus élevée que la vitesse de

diffusion de l'eau, de l'intérieur vers la surface. Il se forme alors une croûte relativement imperméable à la surface et qui retarde tout séchage subséquent. A ce point de vue, le séchage du capelan frais est comparable à celui de la morue salée.

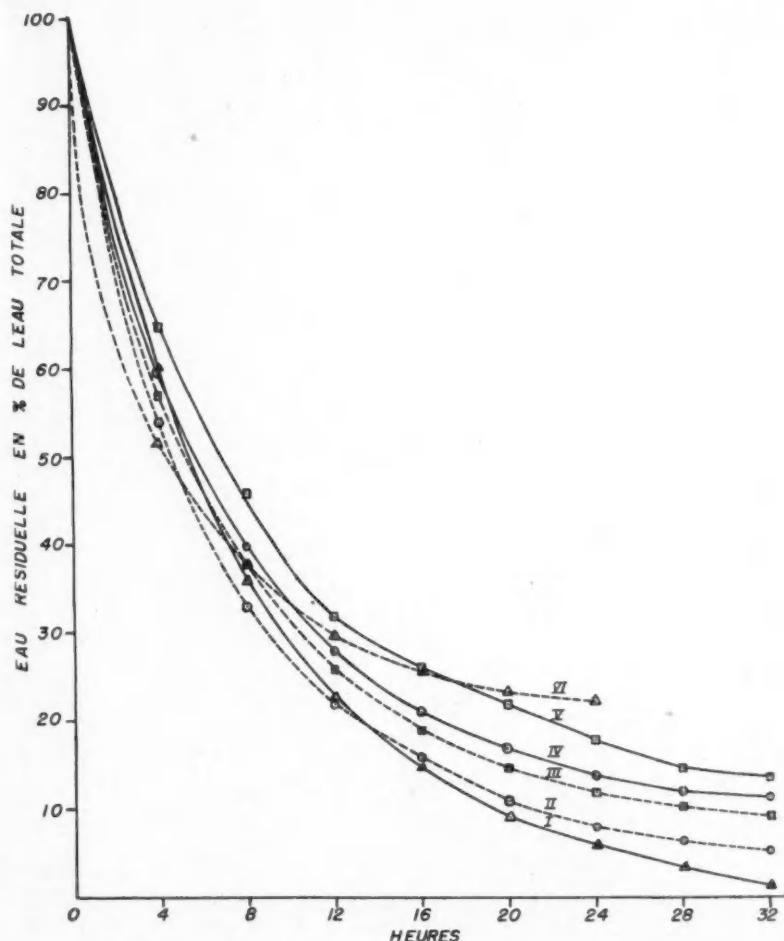


FIGURE 2. L'allure du séchage du capelan en fonction de la température et de l'humidité relative, le courant d'air étant constant à 150 cms. à la seconde.

----- .50% H.R. ————— 60% H.R.  
I et VI, 35°C.; II et IV, 32.2°C.; III et V, 26.7°C.

Lorsque le séchage de la morue est trop lent, le sel diffuse avec l'eau pour ensuite cristalliser à la surface du poisson. Dans des conditions semblables, ce phénomène ne peut avoir lieu avec le capelan frais, car il ne contient pas de sel, mais, par contre, il a tendance à se décomposer. Ainsi, l'humidité relative de

60%, à la température de 35°C (95°F), peut être considérée comme l'humidité extrême pour le séchage du capelan.

Une mince croûte à la surface du poisson, au début du séchage, est dans une certaine mesure nécessaire, pour empêcher les bactéries d'envahir la surface

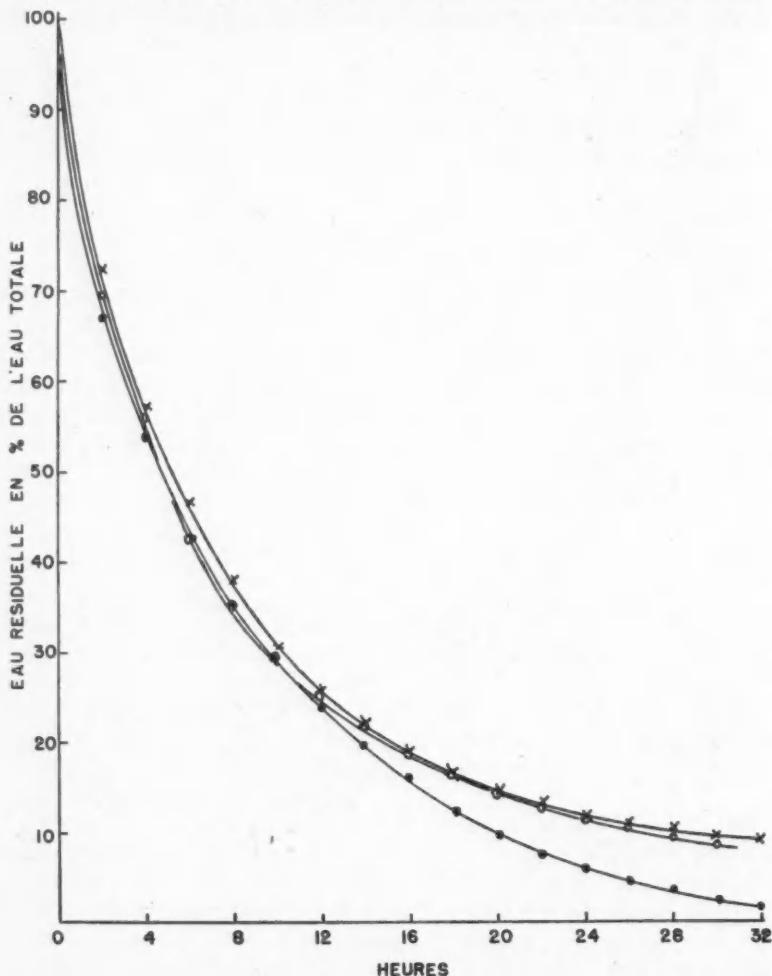


FIGURE 3. Influence de la vitesse de l'air sur l'allure du séchage du capelan à 26.7°C.; 50% H.R.  
—X— 150; —●— 250; —○— 300 cms. la sec.

de la partie épaisse de la chair. Quant aux viscères, ils sèchent un peu plus lentement que la chair épaisse du dos, mais rien n'indique au cours du séchage qu'ils subissent une décomposition avancée.

A la température de 35°C (95°F) et à l'humidité relative de 60% (figure 2), 20 heures de séchage suffisent pour réduire la teneur en eau du capelan à 42% base sèche (30% base humide).

### VITESSE DU COURANT D'AIR

Quelques expériences ont été tentées à des vitesses de courant d'air de 250 cms. à la seconde (500 pds. à la minute) et de 300 cms. à la seconde (600 pds. à la minute).

A la température de 26.7°C (80°F) et à l'humidité relative de 50% (figure 3),

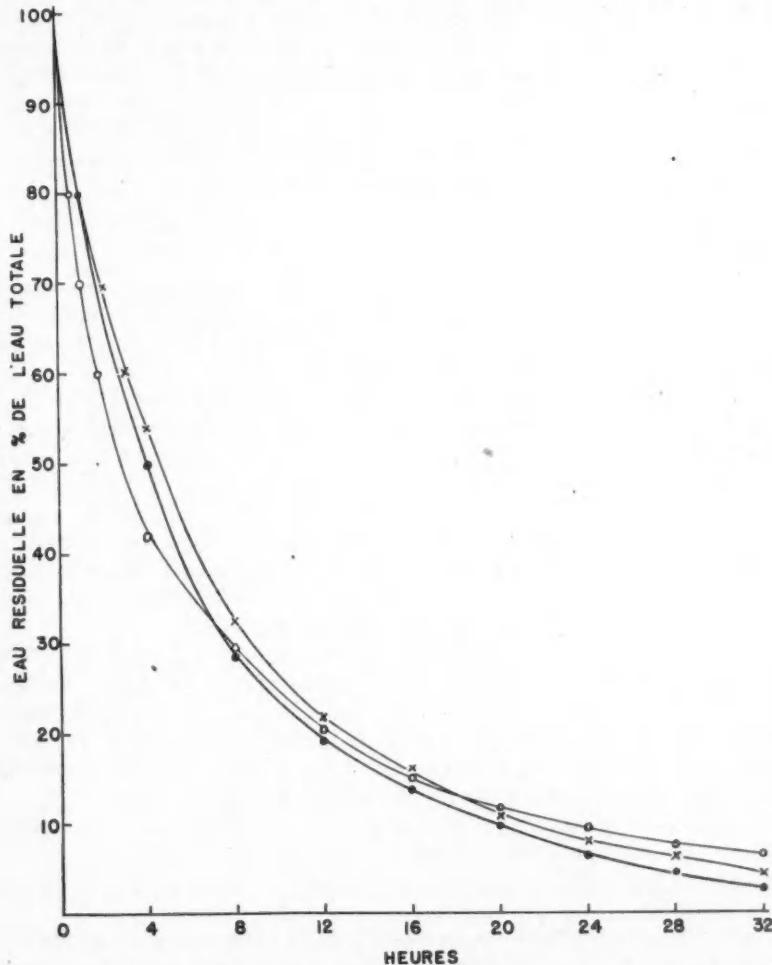


FIGURE 4. Influence de la vitesse de l'air sur l'allure du séchage du capelan, à 32.2°C.; 50% H.R.  
—x— 150; —●— 250; —○— 300 cms. la sec.

une augmentation sensible de la vitesse du courant d'air accélère la vitesse du séchage. En effet, un courant d'air de 250 cms. à la seconde (500 pds. à la minute) à ces conditions de température et d'humidité relative donne des résultats semblables à ceux que peuvent produire les conditions de séchage dont

la température, l'humidité relative et la vitesse du courant d'air sont de 35°C (95°F), de 60% et de 150 cms. à la seconde (300 pds. à la minute) respectivement. Dans ces mêmes conditions de température et d'humidité relative, une vitesse de courant d'air de 300 cms. à la seconde (600 pds. à la minute) ne donne aucun résultat avantageux.

A 32.2°C (90°F) et à 50% d'humidité relative (figure 4) un courant d'air d'une vitesse d'au delà de 150 cms. à la seconde (300 pds. à la minute) n'a aucun effet d'importance sur la vitesse de séchage. A 300 cms. à la seconde (600 pds. à la minute) la vitesse initiale de séchage est rapide, mais elle fléchit trop rapidement par la suite; ce qui est tout à fait normal puisqu'une augmentation de la vitesse du courant d'air équivaut à une diminution de l'humidité relative. Ces conditions favorisent alors la formation rapide d'une croûte relativement imperméable à l'eau qui diffuse de l'intérieur vers la surface.

#### L'EAU D'EQUILIBRE

L'introduction sur le marché des produits alimentaires séchés a suscité un intérêt croissant dans la relation qui existe entre la teneur en eau de ces produits et l'humidité relative ambiante. Durant la dernière guerre, cet intérêt s'est porté surtout sur les aliments destinés aux forces armées et sur le matériel d'emballage de ces aliments (Wink 1946). En général, les travaux de ce genre ont trait à toutes substances plus ou moins hygroscopiques, soit pour déterminer la limite d'humidité relative à laquelle elles peuvent être séchées, soit pour servir de guide dans le choix des conditions idéales d'entreposage.

Ainsi, des données relatives à l'eau d'équilibre du capelan séché peuvent fournir des renseignements utiles sur la protection de ce produit contre l'absorption d'humidité et contre le développement des moisissures durant la période d'entreposage. Ces renseignements seraient en outre utiles à l'étude de la perméabilité du matériel utilisé pour l'emballage de ce produit.

L'eau d'équilibre a donc été déterminée aux températures de 22.5°C (73°F), 26.7°C (80°F) et 32.2°C (90°F), pour des humidités relatives variant de 44% à 93%. Le capelan utilisé pour ces expériences était au préalable séché jusqu'à concurrence d'environ 42% d'eau base sèche (30% base humide). Chaque courbe (figure 5), représente la moyenne de 3 expériences. Ce sont des données d'absorption, aucun essai n'ayant été fait sur du capelan non séché.

Comme dans le cas de la morue fortement salée, étudié par Cooper (1938), pour une humidité relative donnée, une variation de température dans les limites de 22.5°C à 26.7°C ne change pas le pourcentage d'eau d'équilibre dans le capelan frais.

La différence entre la courbe de 32.2°C (90°F) et les autres s'explique peut-être par le fait qu'à cette température, et surtout aux humidités relatives élevées, le poisson se décompose rapidement et la constitution physique du capelan change.

En général, le capelan perd ou absorbe de l'eau suivant l'humidité relative ambiante. Ainsi, la perte ou l'absorption d'eau cessent au moment où la teneur en eau du capelan atteint sur la courbe le point qui correspond à l'humidité relative du milieu.

Il est alors évident, d'après ces expériences, que pour maintenir du capelan à 42% d'eau base sèche (30% base humide) l'humidité relative d'entreposage, dans les limites de température de 22.5°C à 26.7°C, doit être à 85%.

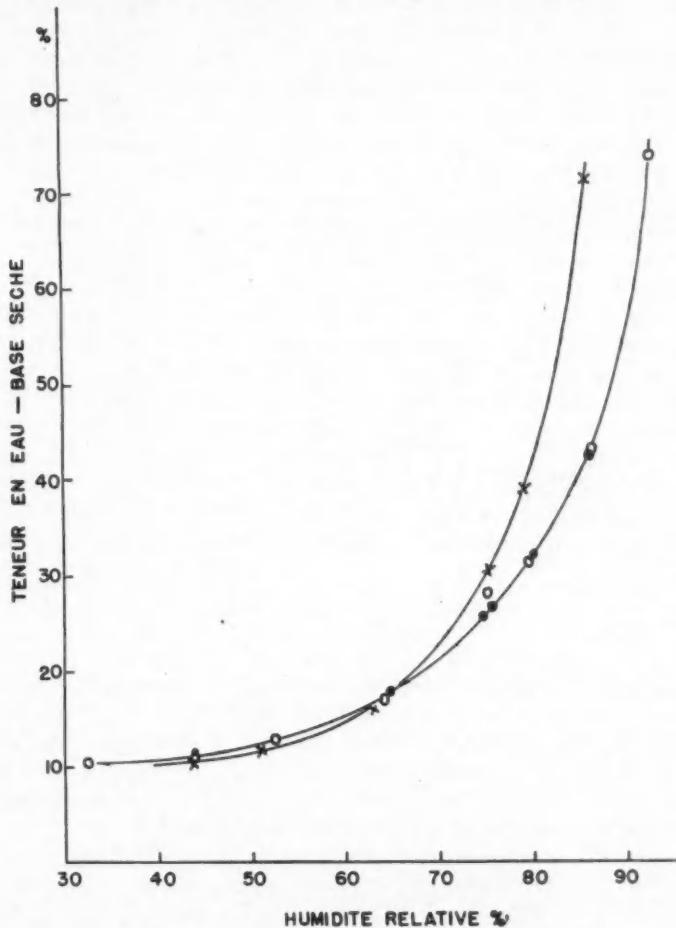


FIGURE 5. Pourcentage d'eau d'équilibre dans le capelan en fonction de la température et de l'humidité relative.

—●— 22.5°C.; —○— 26.7°C.; —×— 32.2°C.

#### MOISSISURES

L'entreposage du capelan n'est pas régi seulement par sa teneur en eau. Un autre facteur d'importance égale et qui mérite considération est le développement des moisissures à la surface de ce produit. Il faut donc trouver des conditions d'entreposage qui retardent au moins le développement de ces organismes.

L'apparition des moisissures a été étudiée à diverses humidités relatives pour 3 différentes températures. Dans le tableau II, le signe (+) indique que des moisissures ont paru à la surface des échantillons. Ce signe est accompagné du nombre de jours qu'elles ont pris à se développer et à devenir visibles à l'oeil nu. Le signe (-) indique qu'il n'est apparu aucune moisissure du moins pendant le temps indiqué.

Tous les échantillons utilisés dans cette étude avaient une teneur en eau voisine du pourcentage d'eau d'équilibre correspondant à l'humidité relative à laquelle ils devaient être exposés. La température de 32.2°C (90°F) a été éliminée pour les raisons qui ont été signalées précédemment.

TABLEAU II. Développement des moisissures sur le capelan séché en fonction de l'humidité relative, de la température et du temps.

T°	Humidité relative (%)				
	93	86.6-86.3	80.3-79.4	75.7-75.1	70
20.0°C. 68.0°F.	(+) 5 jours	(+) 7 jours	(+) 11 jours	(-) 20 jours	(-) 30 jours
22.5°C. 73.0°F.		(+) 7 jours	(+) 15 jours	(-) 20 jours	(-) 30 jours
26.5°C. 80.0°F.	(+) 9 jours	(+) 5 jours	(+) 13 jours	(+) 15 jours	(-) 30 jours

Le tableau II révèle qu'un entreposage à une humidité relative de 75% environ est praticable à condition que la température n'atteigne pas 26.7°C (80°F), car à cette température des moisissures se développent au point de devenir visibles au bout d'environ 15 jours. Or, une humidité relative de 75% aux températures des expériences, correspond à peu près à un pourcentage d'eau d'équilibre de 26% base sèche (20% base humide).

Ces résultats correspondent sensiblement à ceux de Macara (1943) sur le développement des moisissures sur la viande de boeuf séchée. Il a constaté que dans les limites de température de 20°C à 37°C, *Aspergillus* et *Penicillium* commencent à apparaître à l'humidité relative de 75% et qu'ils ne se développent pas aux humidités inférieures à 70%.

#### CONCLUSIONS

Des expériences ont été faites dans le but de déterminer les conditions optimales de séchage du capelan frais. Il a été constaté que la vitesse du séchage était d'autant plus rapide que le capelan était plus petit, et que les caractéristiques de séchage du capelan décongelé étaient les mêmes que celles du capelan frais. Un courant d'air d'une vitesse de 250 cms. à la seconde (500 pds. à la minute), à

une température de 26.7°C (80°F) et à une humidité relative de 50%, donne les mêmes résultats de séchage qu'un courant d'air d'une vitesse de 150 cms. à la seconde (300 pds. à la minute), à une température de 35°C (95°F) et à une humidité relative de 60%. Ces deux conditions ont été choisies comme étant les plus efficaces au point de vue de vitesse de séchage.

Afin de pouvoir signaler les conditions optima d'entreposage, le pourcentage d'eau d'équilibre a été déterminé sur du capelan séché à différentes températures en fonction de l'humidité relative. Le développement des moisissures a aussi été suivi sur le capelan séché. Les résultats permettent de conclure que la limite optima d'humidité relative pour l'entreposage du capelan séché est aux environs de 75%. Mais il ne faut pas que la température d'entreposage atteigne 26.7°C (80°F), car à cette température des moisissures apparaissent à la surface du poisson après 15 jours environ. A 75% d'humidité relativé toutefois, le pourcentage d'eau d'équilibre du capelan est d'environ 26 base sèche (20% base humide). Ce qui veut dire que, pour conserver son poids et être exempt de moisissures, le capelan destiné à un entreposage plus ou moins prolongé doit être séché jusqu'à concurrence de 26% d'eau, base sèche (20% base humide) et entreposé dans une atmosphère qui ne dépasse pas 75% d'humidité relative. D'autre part, s'il est entreposé à 75% d'humidité relative, mais avec une teneur en eau de 40%, il continue de sécher jusqu'à concurrence de 26% qui est son pourcentage d'eau d'équilibre pour cette humidité relative.

Nous tenons à remercier Monsieur Yvan Kirouac, étudiant employé durant la saison d'été, pour son assistance technique qui a grandement contribué à la réalisation de ce travail.

#### RÉFÉRENCES

- COOPER, D. L. Studies on salt fish. III Equilibrium moisture coefficient of salt fish muscle. *J. Fish. Res. Bd. Can.*, **4** (2), 136-140, 1938.
- COOPER, D. L., AND A. L. WOOD. Experimental drying. *Trans. Amer. Soc. Mech. Engrs.*, **62**, (7), 621-625, 1940.
- DUNLAP, W. C. Vacuum drying of compressed vegetable blocks. *Ind. Eng. Chem.*, **38** (12), 1250-1253, 1946.
- FIEGER, E. A. AND C. W. DUBOIS. Conditions affecting quality of frozen shrimps. *Refrig. Eng.*, **52** (9), 225-228, 1946.
- INTERNATIONAL CRITICAL TABLES. **1**, 67-68, First ed. McGraw-Hill Book Co. 1926.
- LINTON, E. P. AND A. L. WOOD. Drying of heavily salted fish. *J. Fish. Res. Bd. Can.*, **6** (5), 380-391, 1945.
- MACARA, T. J. R. Growth of molds on dried meat. *J. Soc. Chem. Ind.*, **62** 104-106, 1943.
- SIGURDSSON, G. J. Studies on the storage of herring in refrigerated brine. *Proc. Inst. Food Tech.* **1945**, 91-114, 1945.
- WALKER, W. H., W. R. LEWIS AND W. H. McADAMS. Principles of chemical engineering, Second ed. McGraw-Hill Book Co. 1927.
- WINK, W. A. Determination of moisture equilibrium curves of hygroscopic materials. *Ind. Eng. Chem. Anal.*, **18**, 251-252, 1946.



